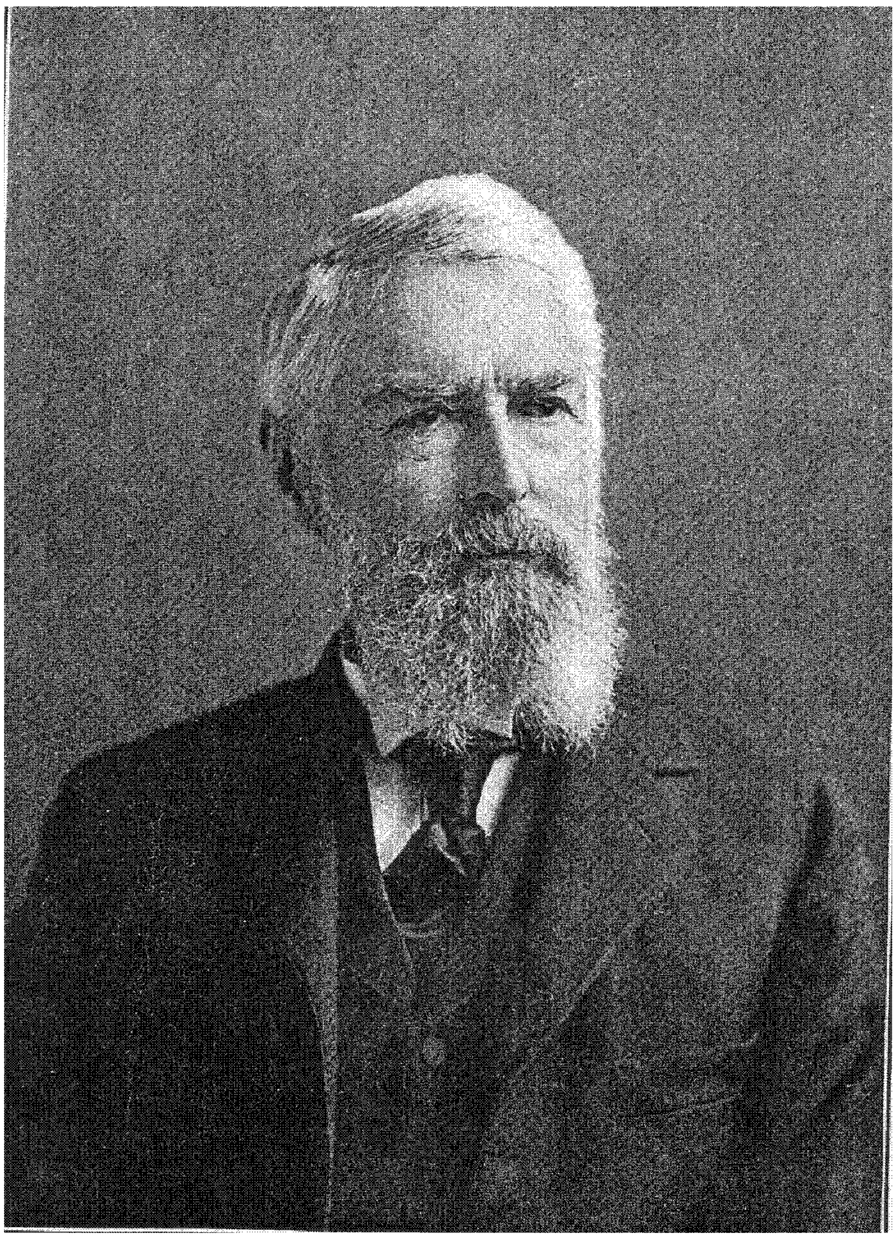
GENERAL HERMAN HAUPT, AIR CAR ADVOCATE



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REMINISCENCES

OF

GENERAL HERMAN HAUPT

Director, Chief Engineer and General Superintendent of the Pennsylvania Railroad
Contractor and Chief Engineer for the Hoosac Tunnel
Chief of the Bureau of United States Military Railroads in the Civil War
Chief Engineer of the Tidewater Pipeline
General Manager of the Richmond & Danville and Northern Pacific Railroads
President American Air Power Company
Etc Etc

GIVING

HITHERTO UNPUBLISHED OFFICIAL ORDERS,

PERSONAL NARRATIVES OF IMPORTANT MILITARY OPERATIONS,

AND

INTERVIEWS WITH PRESIDENT LINCOLN, SECRETARY STANTON, GENERAL-IN-CHIEF HALLECK, AND WITH GENERALS MCDOWELL, MC-CLELLAN, MEADE, HANCOCK, BURNSIDE, AND OTHERS IN COMMAND OF THE ARMIES IN THE FIELD, AND HIS IMPRESSIONS OF THESE MEN

[WRITTEN BY HIMSELF]

WITH NOTES AND A PERSONAL SKETCH BY
FRANK ABIAL FLOWER

Illustrated from Photographs of Actual Operations in the Field

1901

GENERAL HERMAN HAUPT.

GENERAL HAUPT, now in his 85th year and the active head of an important manufacturing enterprise in the United States, is one of the most interesting, as he certainly is one of the most remarkable, figures in our history.

Few men have participated in so much that has contributed to the growth and grandeur of our country, yet how little the world knows of his career, how reluctant the trumpeters have been to herald his achievements!

A designer and builder of roads and bridges; a constructor of railroads and tunnels; a professor and author; an inventor and master mechanic; a military strategist and civil counsellor; a railway manager and canal engineer; a manufacturer and organizer of great enterprises; a military and civil engineer, still up-to-date and a leader of progress, he links the old with the new, the slow and sleepy past with the swift and dashing present in a way that is entirely exceptional.

He was born in Philadelphia on March 26, 1817. His father, Jacob Haupt, died in 1828, leaving a widow and six children.

WEST POINT COMMISSION DATED AHEAD.

In 1830, through the help of John B. Steriger, Member of Congress from Pennsylvania, he received an appointment to West Point from President Andrew Jackson; but as he was only 13, the commission was dated a year ahead. He entered in June, 1831, at the age of 14, and graduated in 1835, at the age of 18, in a class with General George G. Meade and others who became distinguished in the civil war.

Of that early class of fifty-six members, there are no survivors except General Haupt, and in the entire list of graduates of the United States Military Academy the only senior is General Thomas A. Morris (1834) of Indianapolis, Ind.

In the fall of 1835 he resigned his commission in the army to

Finally he secured permission from the County Commissioners of Baltimore to lay his line on a county bridge, high over the tracks, thus defeating the railroad and reaching tidewater in safety.

Without the power of eminent domain to condemn rights-of-way for hundreds of miles through the property of those recalcitrant holders who are encountered in every great enterprise, and surrounded and watched everywhere by the hostile agents of the most powerful corporations in the United States, Haupt's pipe-line achievement stands as one of the most remarkable feats of its character in this country, and is the one in which, perhaps, he takes the greatest pride.

The Tidewater Pipeline, which Haupt's success rendered possible, is now, as it has been for many years, in successful operation, with offices on Broadway, New York, and is one of the decisive elements which combined to give cheap illuminating fluid to the people of the entire nation, while, at the same time, the members of its original enemy, the Standard Oil Company, have been able to accumulate fortunes that are really fabulous in size, due in part to the system of trunk pipe-lines like Haupt's now in general use under the general law subsequently passed.

In 1879 General Haupt was employed to examine and report upon Hardie's pneumatic motors, five of which were constructed and tested upon the Second Avenue Railroad in New York. A compression plant was erected in Harlem, from which air at a pressure of 360 pounds was introduced into cylinders placed under the car seats. The motors were entirely successful, but were never generally introduced.

Haupt demonstrated that the cost of transporting passengers by horse power, including general expenses and a 6 per cent. dividend, was 4.55 cents each, and by pneumatic motor 2.57 cents each.

Such a result was entirely revolutionary, but the projectors could not get their motors upon the roads.

In the same year (1879) General Haupt was appointed consulting engineer of the United States Hydrogen Company, a corporation engaged in developing processes for the anti-corrosive treatment of iron and steel. Many of the results were entirely satisfactory, and articles treated by these processes resisted even the attacks of aqua regia.

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Reminiscences of General Herman Haupt

Limited Autograph Edition

Signed Herman Haupt

IN JULY, 1901.

THE
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COMPRESSED AIR FOR STREET-CARS.

By General Herman Haupt, C. E.

In view of the objections to the overhead electric system for propulsion of cars on surface roads in cities, the annoyance from tearing up streets and the cost of plant and maintenance of the cable lines, the expense of horse power, with the sanitary evils resulting from the location of stables in populous cities, the fact that pneumatic motors, after a successful demonstration of their superiority, have been largely overlooked seems inexplicable.

These motors not only are entirely free from the objectionable features of the other systems, but they furnish a mode of propulsion which is more safe and more economical than any other with equal velocity of transit. These assertions are made advisedly and are based on actual demonstration.

In 1878 and 1879 five pneumatic motors were constructed upon the plans and under the supervision of James Hardie, Mechanical Engineer, and were run for several months on the Second-avenue railroad in New York with perfect success. In 1879 the writer was called upon in the interest of proposed investors to investigate and report upon the practicability and expediency of using pneumatic power for street railroads. The comparative results were overwhelmingly in favor of motors of this class, but all attempts to secure their general introduction at that time proved failures.

The position taken by the officers of horse-railroad companies, both in New York and Philadelphia, was that any car running along city streets without horses in front would frighten horses, cause runaway accidents and subject companies to suits for damages. This objection of course applies with much greater force to the cable and trolley systems, which are accompanied by a loud humming noise, while the pneumatic motor can have a noiseless exhaust; but no argument or explanation availed in the face of this senseless objection. One railroad president declared that if the motor were adopted by his company it would be necessary to kill some of his old horses, stuff the skins and mount a pair of them on a low truck in front of each car!

The attempt to introduce pneumatic motors was thus found to be premature in 1879. The company could make no progress and finally abandoned all effort, losing the capital expended in plant and demonstration, and no attempt to revive the motor has since been made. But the engineer and inventor, Robert Hardie, now in the service of the mechanical department of the Columbian Exposition at Chicago, retains unshaken confidence in the superiority of the pneumatic motor.

Conditions existing now seem favorable for the introduction of a motor which, free from the objections to all other systems, with no new defects of its own, may be considered as perfect. No fears are now entertained that a car running without horses in front will make a stampede of all equines on the streets traversed, and this in 1879 was the only reason urged in opposition to the introduction of the pneumatic motor. It is possible, therefore, that a few extracts from the report made in 1879 may be of interest at this time.

The compression-plant was located in Harlem in New York, on the line of the Second-avenue railroad. It developed 66 horsepower and charged the cylinders under a car with compressed air in seven minutes. With proportionately larger plant not more than one minute would be required. The report of Mr. Hardie stated the capacity of the cylinders under the seats at 17,000,000 foot-pounds of work, capable of running a car sixteen miles on a level. The effect of the compressed air was greatly increased by passing it through a tank of hot water at the temperature due to 8o pounds pressure. The tank had a capacity of five cubic feet and was placed on the side of the platform.

The writer has not at hand a copy of his full detailed report, but only an abstract of some of the results, which will be given here. A duty of nearly 50 per cent. of the horse-power used in compressing air can be secured from the expansion and utilization of dry air when compressed; and, by using stationary, compound or condensing engines, four times the power can be obtained with a given cost of fuel, as compared with ordinary steam-motors, which more than counterbalances the loss in compression. By the addition of a heater and passing the air through hot water an increase of nearly 100 per cent. power can be secured at a merely nominal cost.

On a straight and level road, with 160 cubic feet of air in the reservoirs, under an initial pressure of 350 pounds, the motor would run seven miles with a reserve of one-third left in the reservoirs on its return. This result assumes that the amount of air expended at each stroke is equal to a full cylinder of air expanded to atmospheric tension, but actual work has demonstrated an ability to run ten miles with a single charge, proving that less than this quantity is sufficient. The back pressure which would result from working against a vacuum is relieved by suction valves in the exhaust passages.

In descending grades the motor cylinders act not only as brakes, but also as air-pumps, and have power to pump back into the reservoirs, against a pressure of 200 pounds, sufficient air to raise the gage-pressure seven pounds in running 2100 feet, and restore sufficient air, when heated, to run the motor half that distance upon a level. By this remarkable contrivance power can be stored on, descending grades. The down-hill portions not only use no power, but give back a portion of that which was expended in ascending.

The compressed air can be used expansively to any extent, and cut off at any part of the stroke. It can act as a brake, or the motor can be instantly reversed, and the braking apparatus is exceptionally complete and satisfactory.

The power of an eight-ton motor is sufficient to propel three cars on a straight and level road. With full power in the motor cylinders and full adhesion on the rails the motor can overcome grades of 300 feet to the mile.

Although, during a run, the pressure in the reservoirs is constantly diminishing, yet, by means of a reducing valve, the working pressure in the motor cylinders is maintained at a constant limit.

Each motor, allowing for increased speed, would take the place of ten or fifteen horses, the cost of which would about equal the cost of the motor, $1500.

The system would be particularly adapted to suburban localities and would afford better facilities for rapid transit than are now afforded by elevated roads, for while the speed would be equal to twenty miles or more per hour, the stops need not be limited to stations, but could be made at any point.

With the small class of motors, three cars, or two in addition to the motor, can ascend grades as steep as any usually found on horse railroads. This is a point of the greatest value

for public accommodation. It will enable a company to utilize all its old cars and supply additional cars at the hours when the rush of travel requires them without additional expense for power or conductors.

The Delamater Iron Works offered to supply a compression plant of sufficient capacity to charge one car per minute for $20,000.

Compressed air can be transmitted to any distance without loss except for friction in pipes. If pipes are large and velocity low the loss will be inconsiderable. Several lines could therefore be operated from a large central plant and in many localities natural water-powers could be utilized to compress air and the compressed air transmitted by pipes to charge motors, generate electric currents, or drive machinery by direct application to cylinders.

To charge motors at a central station a nozzle between the tracks and a short piece of pressure-hose to screw on to the air reservoir is all that would be required to connect with reservoirs located in a building. It would not be necessary to run the cars into a house to renew the air-supplies.

The running expenses are less than one-half--in fact, the estimate shows less than one-third--the cost of horse power. The motors run without noise, ashes or smoke, are perfectly under control and would furnish the best possible power to operate elevated railroads. Skilled engineers are not required. An ordinary cardriver can be taught to run an engine in a single trip.

No flues can be burned or boilers exploded though carelessness, and as air-reservoirs last indefinitely, explosions in transit from causes which render steam dangerous are impossible. Even if an explosion should occur by a rupture it would be while charging the reservoir at the time of maximum pressure and not in transit, and the air would simply escape with a hissing sound ; cold, not heat, would result from the expansion.

The car acts as its own governor and no more air can be used than is necessary to overcome the resistance ; there can be no waste. There are no horses in front to obstruct a clear view of the track. At a speed of twelve miles per hour the motor can be stopped on a level within its length, and the braking apparatus cannot get out of order so long as the motor can move at all.

The pneumatic motor would be peculiarly adapted to underground roads, as the escape of pure air would assist in the ventilation, but it is the best possible for all urban or suburban roads, whether elevated, surface or in tunnels.

In this paper results only have been given, but the full report made in 1879 gives the facts upon which the conclusions have been based.

A detailed estimate was made from data furnished by the operations of the Second-avenue railroad and a comparison of cost of operation by horse power and by the pneumatic motor. In this estimate it was assumed that a compression plant was located at each end of the route, requiring double the expenditure for plant and double the expense of operation over a single plant located in the middle of the run, which would answer just as well. The estimate for pneumatic power was designedly made in excess, so that errors would be on the safe side, and the cost of horse power was from actual results on the Second-avenue railroad.

On the basis of 16,000,000 passengers carried on this road in 1878, the year previous to the report, the actual results of operation by horse power were :

Running expenses per passenger in cents	2.88
Estimate by pneumatic motor	0.93
Cost per passenger by horse power, including general expenses and a six percent. dividend	4.55
Estimate by use of pneumatic motor	2.57

The dividend was $72,000 = 0.45 cents per passenger.

The conclusion from the data furnished was that a very small increase in the number of passengers would permit the company to sell ten tickets for 25 cents and still pay fair dividends upon the capital invested, besides furnishing a rapid transit the speed of which would be limited only by considerations of safety.

But all these demonstrations and representations, backed by the very strongest indorsements of the daily press in New York and by the actual running of five motors daily for a period of several months, availed nothing against the senseless cry, "It will scare horses," or, "The motor cannot be run unless we put stuffed horses in front of each car." It is true that horses on the opposite track did at first prick up their ears, look at the motor and shy a little, but they never gave any trouble and soon became accustomed to it, and no case of a runaway accident with street vehicles was heard of, but prejudice, which proved all powerful to exclude the pneumatic motor at that time, did not prevent the introduction of the trolley and cable systems very soon afterwards.

STREET RAILWAY MOTORS:

WITH

DESCRIPTIONS AND COST OF PLANTS AND OPERATION OF THE VARIOUS SYSTEMS IN USE

OR PROPOSED FOR

MOTIVE POWER ON STREET RAILWAYS.

BY

HERMAN HAUPT, C. E.

CHIEF OF BUREAU OF MILITARY RAILROADS DURING THE LATE WAR; LATE CHIEF ENGINEER PENNSYLVANIA R. R.; GENERAL MANAGER NORTHERN PACIFIC R. R.; PIEDMONT AIR LINE; CHIEF ENGINEER TIDE WATER PIPE LINE.

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VI.

THE PNEUMATIC OR COMPRESSED AIR MOTOR.

After an extended investigation, commenced in 1879 and continued recently, with a long interval for observation of other systems, the writer is confirmed in his original conclusion that, for the operation of city and suburban roads—whether surface, elevated, or underground —no other motive power can compare favorably with compressed air, either in cost of plant, economy of operation, freedom from all objections, or the possession of incidental advantages.

Those who have not examined the subject almost invariably object that double the power is required to compress air that can be utilized in actual work from the air where compressed, and assume a necessary serious loss.

It may be true that double the power may be required; but suppose the air is compressed by a water-power, otherwise unemployed, that costs nothing except the first outlay for the machinery for its utilization: might not the power be cheaper than steam, even if only 10 per cent. could be utilized?

The actual facts are that air can be compressed by the use of the best compound expansion stationary engines in which double the useful effect can be secured per pound of coal as compared with steam motors. This alone would at once place air on a par with steam; but in stationary engines a quality of coal can be used that costs less than half as much as the coal required for locomotives, and this raises the economy of air to double that of steam in small motors.

But this is not all. It has been proven by repeated tests, both in Europe and America, that the simple device of passing the air through a small tank of hot water before admission to the motor cylinders again doubles the useful effect, and at the same time prevents all inconvenience from the production of frost at the exhaust, and this makes the economy 4 to 1 as compared with steam, the cost of reheating being merely nominal.

In fact, air is the cheapest power that can be used for

the operation of street railways, and it is one against which none of the objections that apply to other systems can be urged. Why capitalists and engineers have neglected it so long is beyond comprehension. It can only be explained upon the ground of ignorance of facts from failure to investigate.

Air can be transmitted to long distances without any loss by condensation or radiation, as with steam; and the loss by friction, in pipes of proper diameter, is inconsiderable, even at a distance of miles.

The importance of air as a motive power for city railroads demands a careful consideration of its claims.

Properties of Air.

Air is composed of about 23 parts by weight of oxygen and 77 parts of nitrogen.

By volume the proportions are 21 of oxygen to 79 of nitrogen.

At a temperature of 60° F., its weight is $\frac{1}{815}$ that of water = 0.0765 lb. per cubic foot.

At a temperature of 32° 12.433 cubic feet = 1 pound.

The specific heat of air at constant pressure and with increasing volume is 0.2377, water being 1.

In doubling the volume of air the units of heat expended are, as given by Clark, 117.18 (other authorities, 115.8).

If the temperature be doubled without adding to the volume, the units expended will be 83.22. To double the volume in addition requires 33.96. Total, 117.18.

The specific heat of air in raising temperature without increase of volume is 0.1688.

In compressing air from a temperature of 60° to one-half its volume under an effective pressure of 15 lbs. to the square inch the temperature will be raised to 177°, and the increment of temperature will be 117°. But in continued compression to 30, 45, 60, 75, 90, 105, and 120 pounds the temperatures are successively 255°, 317°, 369°, 416°, 455°, 490°, and 524°, and the successive increments 77°, 62°, 52°, 47°, 39°, 35°, 34°.

The capacity of air for holding moisture is affected by its volume and temperature, but apparently not by its density. It appears from observations made by manufacturers of compressed plant that air compressed to 50 atmospheres contains no more water than air at the same temperature under one atmosphere, consequently $\frac{49}{50}$ of the water is removed during compression, and the air becomes so dry that no frost can be formed in the exhaust. Even when air is cooled by passing through water no additional quantity of moisture can be taken up. The compressor used on the Second Avenue Railroad in 1879 cooled the air by passing it through a tank of water under pressure, yet no frost was formed at the exhaust. It is now considered preferable, in the most improved construction, to cool the air without direct contact with water.

As every thermal unit is equivalent to 772 pounds raised one foot, it is evident that if air could be compressed without elevation of temperature and loss of heat in cooling much would be gained. Something has been accomplished in this direction, but complete isothermal compression is unattainable. Adiabatic compression, or compression attended by evolution of heat, is alone possible; but at high pressures the loss is proportionately less, as has been shown, and the storage capacity of reservoirs is, by increased pressure, increased for longer runs.

It was observed by Mr. G. H. Reynolds, of the Delamater Works, that the heat liberated in proportion to the power secured was much less at high than at low pressures. Satisfactory explanation can perhaps be given. Imagine a vessel containing one pound of air at ordinary tension 13 cubic feet, the base one square foot and height 13 feet. If, by means of a piston, this air should be forced into one-half the space, or $6\frac{1}{2}$ feet, the pressure would be increased to 30 pounds, and the work done would be 21,528 foot-pounds. One pound of water raised 1° is equivalent to 772 foot-pounds, and as the specific heat of air is 0.238, 772 × 0.238 = 184, the foot-pounds expended in heating 1 pound of air 1°. Then 21,528 ÷ 184 = 116° = the heat liberated in compressing one pound of air into half its volume.

Now suppose the $6\frac{1}{2}$ cubic feet of air should be again compressed one-half, or to $3\frac{1}{4}$, the final pressure would be 60 pounds, and the space $3\frac{1}{4}$ feet, and the work 21,528 foot-pounds as before, representing 116° of heat. But with these 116° of heat the pressure has been increased from 2 atmospheres to 4, and in like manner from 4 to 8, from 8 to 16, and from 16 to 32, would each require but 116°, and at the end 16 atmospheres of additional pressure have liberated only as much heat as one atmosphere at the commencement; assuming that the heat when liberated has been absorbed so as to secure isothermal contraction of volume.

It must be remembered, however, that if the pressure should be increased to 16 atmospheres, the volume would be diminished to $\frac{1}{16}$, and if the air should be used at full pressure throughout the stroke of a piston no advantage would be gained. Very high pressures are, however, always used expansively, and if air at 500 pounds should be cut off at $\frac{1}{16}$ of the stroke, the gain over an equal weight of air at 250 pounds cut off at $\frac{1}{8}$ would be 32 per cent.

Where temperature is considered, the results are quite different. The tables for adiabatic compression give from one atmosphere to two, an increase per one atmosphere of 115.8°. At 8 atmospheres the increase is 36.1, at 10 atmospheres 30°, at 15 atmospheres 25.4°, and at 25 atmospheres 16.7° per atmosphere: showing

that the increase of temperature during compression is greatest at low pressures.

The largely extended use of compressed air for engineering purposes has led to great improvements in air compressors, and responsible parties can now be found to furnish plant and guarantee results at a very moderate cost, thus removing any element of uncertainty. It is claimed that the best compressors now constructed give a result about midway between the isothermal and the adiabatic, and the net loss of power due to clearance is so small as to be practically unworthy of consideration.

The losses by transmission of air through pipes are comparatively slight. It has been stated by competent authority that there is not a properly designed compressed air installation to-day that loses over 5 per cent. by transmission alone. The largest compressed air power plant in America is that at the Chapin mines in Michigan, where the power is generated at the Quinnesec Falls, and transmitted 3 miles. The loss of pressure as shown by the gauge is only 2 pounds. At the Jeddo Tunnel near Hazelton, air under 60 pounds pressure was conveyed 860 feet, and the gauges indicated no difference of pressure. The pipe in this case being $5\frac{3}{4}$ inches in diameter, was very large for the quantity of air used.

The losses in compressed air, it is said, may be reduced to 20 per cent. of the power used by combining the best system of reheating with the best air compressors.

In France, England, and Germany there have been erected during recent years large compressed air installations. In Paris about 25,000 horse-power is transmitted over the city, and is used to drive engines and for many other purposes. A small motor 4 miles from the central station can indicate in round numbers 10 H. P. for 20 H. P. at the station itself, and by combining the American Compound Condensing Corliss Air Compressor with an efficient and economical reheating apparatus, and Corliss or other economical engines, an increase of efficiency of 50 per cent. may reasonably be expected.

The air used in Paris is about 11 cubic feet of free air per minute per indicated horse-power. The ordinary practice in America with cold air is from 15 to 25 cubic feet per minute per indicated H. P. The engines in France were found to consume about 15 cubic feet of air per minute per H. P. without reheating.

The amount of coal consumed in Paris during reheating is trifling. With the reheaters commonly employed, it amounts to from one to two cents per horse-power per day, and these figures, it is said, can be reduced considerably by a more economical system of reheating.

In the transmission of air through pipes, the loss of pressure can be very conveniently and accurately calculated by taking the loss for a given length and diameter of pipe and initial velocity, and determining the loss for any other velocity, diameter, and length, by a simple proportion, observing that the loss of pressure is—

Directly as the length of pipe and square of the initial velocity.

The friction in 1 mile of 6-inch pipe, with an initial velocity of 20 feet per second, is 5.1 pounds per square inch.

Suppose 1500 cubic feet of free air per minute, under 500 pounds pressure or 34 atmospheres, are to be carried 1 mile. What will be the loss by friction?

In this case, the initial volume will be $\frac{1500}{34} = 44$ cubic feet. 44 cubic feet per minute $= 0.74$ cubic foot per second.

A pipe 6 inches in diameter has an area in square feet of 0.127.

$0.74 \div 0.127 = 6$ feet per second, nearly.

Then $5.1 \times \frac{6^2}{20^2} = 0.457$ pound, a very inconsiderable loss in a distance of 1 mile, and the loss in 10 miles would be only $4\frac{1}{2}$ pounds.

In this calculation the initial density of the air is not taken into consideration, and it does not affect the result with an elastic fluid of uniform density; but a general formula, applicable to all elastic fluids, must recognize density, and the loss of pressure in elastic fluids of different densities, other conditions the same, will be directly as the densities. The loss of pressure, for example, in the transmission of steam through pipes will be about half as great as with air, other conditions, except density, being the same.

The cost of hydraulic pipes to resist high pressures has, January, 1893, been obtained from manufacturers.

	Cents.
3-inch pipe per lineal foot	20.82
$3\frac{1}{2}$ " " " "	24.61
4 " " " "	29.26
$4\frac{1}{2}$ " " " "	35.25
5 " " " "	43.51
6 " " " "	54.87
7 " " " "	64.84
8 " " " "	84.90
9 " " " "	115.78

The quantity of air required for running an ordinary street motor of about 18 or 20 horse-power capacity, for a distance of 1 mile upon an ordinary street railway, has been positively and accurately determined by several months' service of the Hardie Motor on the Second Avenue Railroad in New York in 1879, and also by the experience in France and England. On this important point there can be no mistake, and ample evidence can be furnished.

The Hardie combined motor and car, weighing $8\frac{1}{2}$ tons, including passengers, ran $9\frac{3}{4}$ miles on a bad track on the Second Avenue Railroad. The pressure at start-

ing was 360 pounds; at finish, 100 pounds and reservoir capacity 160 cubic feet, giving the quantity of free air at atmospheric pressure expended 2.773 cubic feet = 284 cubic feet per motor-mile, or $33\frac{1}{2}$ cubic feet per ton-mile.

The Mekarski (French) combined motor and car, weighing 8 tons, including passengers, ran $7\frac{3}{4}$ miles on a street tramway with an expenditure of $36\frac{1}{2}$ cubic feet per ton per mile, or 292 cubic feet per car-mile.

The Beaumont (English) locomotive, weighing 7 tons, is claimed by the inventor to be capable of drawing a 5-ton car 10 miles on a street tramway. Capacity of reservoir, 100 cubic feet. Pressure at starting, 1000 pounds per square inch; at finish, not stated, but presumably 80 pounds. This gives a total expenditure of 6.100 cubic feet of free air, or 50 cubic feet per ton per mile, or 500 cubic feet per train-mile of motor and car.

The Beaumont locomotive, of same capacity and pressure, but said to be 10 tons, ran 15 miles light, and without stopping, on a clean steam railway, using 6.100 cubic feet of free air, or 40 cubic feet per ton per mile.

The Scott-Moncrieff combined motor and car, weighing $7\frac{1}{2}$ tons, is claimed to have run 7 miles on a street tramway. Reservoir capacity, 150 cubic feet. Pressure at starting, 390 pounds (26 atmospheres); at finish, not stated, but presumably about 50 pounds, thus using 3450 cubic feet, or $67\frac{1}{2}$ cubic feet per ton per mile, 472 cubic feet per car-mile.

It is thus seen that Hardie and Mekarski produce the best results, owing to the more efficient method of heating. Beaumont heats a little, and Scott-Moncrieff not at all.

It thus appears from all these statements that the Hardie motor gave better results than any other, although the mechanical work was defective owing to cheap construction without the usual facilities for locomotive work, and the runs were over a very bad track. It is certain therefore that a consumption of 300 cubic feet of free air used in the cylinders at a pressure of 56 pounds per square inch will suffice to run the motor one mile.

The reservoir in the Hardie motor had a capacity of 160 cubic feet; but even at 130 cubic feet, and a pressure of 34 atmospheres, 500 lbs. per square inch, the motor could run 12 miles and retain over 60 lbs. pressure at the end of the trip.

The Hardie motor when towing two cars used 480 cubic feet of air per mile

It has been found that whatever may be the pressure of air in the motor tanks beyond a certain very moderate excess above the working pressure, the additional power expended in compression cannot be made available in propulsion, but is lost in wire drawing the air through the reducing valve to a lower pressure. Consequently all the power expended to secure high pressures in the reservoirs serves only to increase the tank capacity and the length of run.

To avoid this loss, compound engines have been tried, but they are not only unsuited for small motors in consequence of complication, but they have failed to accomplish the object.

Another plan of utilizing the high pressure has been proposed by allowing it to escape through an injector, and thus forcing an additional volume of fresh air into the motor cylinders, reducing to that extent the draft upon the reservoir. It is not known that this plan has been tried, or, if tried, what has been the percentage of gain.

It is, therefore, an interesting question to determine what is the actual loss in high compression measured by coal consumption per mile run.

Assume as data, therefore, that a motor reservoir of 130 cubic feet capacity is to be charged once in two minutes to a pressure of 500 pounds, and determine the value of the coal consumed in raising the pressure from 250 to 500 lbs. per square inch, which coal consumption cannot be again reproduced in work, but represents a loss.

To obtain 130 cubic feet at 500 lbs. or 34 atmospheres, 260 cubic feet at 17 atmospheres must be reduced in volume one-half in two minutes of time. In effecting this compression a piston with an area of one square foot, or 144 square inches, must travel 130 feet in two minutes, with a pressure at the start of 250 pounds per square inch, at the end of 500 pounds and mean of $0.846 \times 500 = 423$ lbs.

The amount of work done in one minute is $423 \times 144 \times \frac{130}{2} = 3{,}959{,}280$ foot-pounds per minute = 120 horse-power.

At $2\frac{1}{2}$ pounds of coal per horse-power per hour, the consumption in 2 minutes for 120 horse-power would be 10 pounds, and as this volume of air at 500 pounds will run the motor 12 miles, with a reserve in the tank at the end of the trip of 20 per cent., the actual consumption for the trip of the coal required for double compression would be but 8 pounds, costing, at $3 per ton for the cheap coal used, $1\frac{1}{2}$ mills per pound, or 12 mills for 12 miles, or one mill per mile run of motor.

It appears, therefore, that notwithstanding the fact that high pressures cannot be directly utilized in propulsion, the cost of producing them is so small, and the advantage of increased storage capacity and increased length of run so great, that it secures great economy to use them, and it is useless to attempt to employ cumbersome mechanical devices to save so inconsiderable a loss, even if there was a prospect of success, which there is not.

If air at 500 pounds could be applied directly to the piston of the motor-cylinders, and cut off at one-sixteenth

of the stroke, the weight of air, or the quantity at atmospheric tension, would be the same as if used at 250 pounds and cut off at one-eighth; but there would be a considerable difference in the work done, as will be seen.

The initial pressure being unity, the average at $\frac{1}{16}$ is 0.236.

The initial pressure being unity, the average at $\frac{1}{8}$ is 0.355.

Then, $500 \times 0.236 = 1.180$.

And, $250 \times 0.355 = 0.888$.

These figures are in proportion to work done, and the difference is 0.292, or 32 per cent. in favor of the higher pressure if it could be utilized.

But the important practical question is: What does this difference cost in money measured by coal consumed? The data are, air per mile 300 cubic feet, 12 miles = 3600 cubic feet. Two-minute intervals = 1800 cubic feet per minute. To compress this volume requires 500 horse-power per hour, or $500 \times 2\frac{1}{2} = 1250$ lbs. coal per hour. 42 pounds in 2 minutes for a run of 12 mills = $5\frac{1}{4}$ mills per mile, and the loss by wire draw 1.31 mills per mile.

But by having 500 pounds pressure in the reservoir instead of 250, the motor can run 12 miles instead of 6, and the cost of compression from 250 pounds to 500 pounds is only one mill per mile, as shown elsewhere: therefore it is great economy to use high pressure, even if there is a loss at the reducing valve.

It may be interesting to give this subject further consideration, and in this connection a quotation from the pamphlet of Mr. Potter becomes pertinent as an introduction. Referring to losses, he remarks:—

By far the greatest loss of all is accounted for by the "wire drawing," which takes place in reducing the storage pressure to a practicable working pressure.

Let it be supposed, for illustration, that this storage pressure is 1000 pounds to the square inch, and that it is reduced to 100 pounds in the locomotive cylinders. It may easily be computed by experts that there will be a loss in this case of over two-thirds of the power originally contained in the air in its high pressure state. Experiments have been made with a view to recovering this loss by direct expansion in the locomotive cylinders, but they have utterly failed, as will now be made apparent.

It seems reasonable and rational to suppose that this would be the proper way to overcome the difficulty, provided that it did not entail too much complication of machinery, and it was accordingly in this manner that Hardie originally attempted it.

Discarding the idea of compounding the cylinders as impracticable, owing to the complication necessarily involved, and other considerations, which will be referred to further on, he designed an experimental engine having two cylinders of equal dimensions and slide-valves as usual, adding cut-off valves and other simple devices which experience had shown to be essential to the economical use of compressed air. The slide-valves were specially designed to balance the high pressure, all parts were proportioned to bear the excessive strains, and the lowest possible storage pressure for the air adopted (360 lbs. per square inch). Upon trial this engine, which was in the form of a combined motor and car, was found to work exceedingly well, running ten miles on a street tramway with one charge of air.

Indicated diagrams, taken at all initial pressures, showed the most beautiful and perfect expansion curves; and indeed, the experiment was regarded as eminently satisfactory. Mr. Hardie, however, being curious to know how much greater was the efficiency by this method than by the use of a reducing valve, had one applied, and found to his great astonishment that the engine worked just as well; that is to say, that it ran as great a distance as before. The engine was carefully examined, but no defects were found, and the experiments were repeated with the same results. Experts were consulted to ascertain, if possible, the reason, and the only conclusion arrived at was that possibly the use of such high pressures in the engine cylinders entailed loss by excessive friction and leakage, which in practice neutralized the theoretical gain. Be that as it may, there was no disputing the facts, and Mr. Hardie, therefore, gave it up and adopted the reducing valve, there being no advantage in straining the machinery with high pressures.

It appears that Colonel Beaumont, in England, has been laboring diligently to effect the same object by compounding the engine cylinders; but as will be seen, his experiments led to the same practical conclusions as those of Mr. Hardie. He begins by presuming that the energy stored in the high pressure air is all, or nearly all, recoverable by expansion in the motor cylinders, and hence argues that the only consideration in fixing the initial pressure is that of conveniently storing the amount of power in a given space. This, he says, is 100 lbs. per square inch in a 7-ton motor having a capacity of 100 cubic feet and of hauling a 5-ton car 10 miles on a street tramway.

Here follows a statement of the practical disadvantage of using compound cylinders upon a street motor which it is not necessary for present purposes to repeat.

Proceeding to investigate the results of the experiment obtained by Beaumont with such an engine, reference is made to a paper read by him on the subject before the Society of Arts and published in the journal of the Society March 18, 1881. On page 389 there is a tabular statement of experimental data, which is here reproduced.

Table of Experimental Data.

Air Pressure.				Minutes.			Pounds.
925 lbs.	run 1000 yards in			9	reduced pressure to		805
805	"	"	"	9	"	"	730
730	"	"	"	9	"	"	660
660	"	"	"	13	"	"	595
595	"	"	"	10	"	"	520

5000 yards run. Loss 405 lbs. in 50 minutes = 3 miles 73 yards per hour.

520 lbs.	run 1000 yards in			10	reduced pressure to		435
435	"	"	"	10	"	"	360
360	"	"	"	10	"	"	288
288	"	"	"	10	"	"	205

4000 yards run. Loss 315 lbs.

If instead of expanding this air freely, it were made to do useful work, from 1000 lbs. down to 200 lbs., and then from 200 lbs. to atmospheric pressure, the work done, upon the whole, would reasonably be expected to be greater than in the latter case alone. Hence, Beaumont's claim to having accomplished great results is readily believed, both by practical and scientific men. That no such perfection is actually obtained in practice, however, will be seen from a careful study of the table. Here let it be observed the pressures are given at the beginning and end of each 1000 yards run, the difference in each case being an exact measure of the quantity of air, and also, when the pressure is taken into account, a measure of the energy expended. Now let these differences be noted :—

First	1000 yards used	. . . .	120 lbs.
Second	" "	. . . .	75 "
Third	" "	. . . .	70 "
Fourth	" "	. . . .	65 "
Fifth	" "	. . . .	75 "
Sixth	" "	. . . .	85 "
Seventh	" "	. . . .	75 "
Eighth	" "	. . . .	72 "
Ninth	" "	. . . .	83 "

From what has been said it would have been expected that as more energy is stored in the higher pressures, these figures should have shown a gradual increase, until the last was about double the first. Neglecting the first as excessive and probably due to some special cause, it is seen that the remaining 8 trips were accomplished on practically the same quantity of air (viz.: an average of 75 lbs. to the square inch, or 5 volumes of the reservoir capacity at atmospheric pressure), but by no means on the same expenditure of energy; and it is particularly noticeable that the eighth trip (or last but one) was accomplished on an expenditure which was less than the average. Hence the inevitable conclusion, that if the higher pressures had been reduced to the average pressure of the eighth trip, at least as good economy would have been attained, showing clearly that Colonel Beaumont's experiments go for nothing more than to confirm Mr. Hardie's experience, and that the advantages claimed for cylinder expansion beyond certain limits are mostly theoretical.

VII.

TESTS OF THE HARDIE COMPRESSED AIR MOTOR.

In 1879 the writer was called upon to investigate and report, as consulting engineer, upon the practicability and relative economy of compressed air as a motive power upon street railways.

At that time five motors had been constructed for the Pneumatic Tramway Engine Company and were in daily use upon the Second Avenue Railroad in New York, by consent of its officers, but at the expense of the Pneumatic Tramway Company, which desired an opportunity of giving the invention a practical test.

The motors were constructed upon plans prepared by Mr. Robert Hardie, a Scotch engineer of remarkable ability, who had been engaged with Scott Moncrieff, of Glasgow, in very successful experiments in that city. Lewis Mekarski, of Paris, had also made successful experiments in the same direction.

The motors and also the compressor plant were constructed at the Delamater Works in New York, but as this establishment did not make a specialty of locomotives and had not at that time the appliances that were necessary to secure the best results, some of the wearing parts were found to be rather soft, a fact which to some extent increased the cost of repairs, but did not discredit the plans of construction. There can, of course, be no more wear on the rubbing surfaces of a pneumatic motor, when properly case-hardened, than on an ordinary locomotive.

The consideration of the applicability of compressed air as a motive power for street engines was taken up with no bias in its favor, and the following extracts from the report, made February 20, 1879, will give the conclusions reached after careful investigation of the motors in actual daily use.

In 1856, while engaged in devising plans for the construction of the Hoosac Tunnel, the writer had, after careful consideration, rejected compressed air, and decided in favor of steam in connection with a vacuum system of ventilation, as more simple, economical, and effectual under the conditions then and there existing in regard to its use, limited financial resources for the purchase of plant being an important consideration.

In any mode of compressing air in which the direct pressure of steam is employed, as in reciprocating pumps, a cylinder of steam unexpanded and at maximum pressure must be expended to secure under high tensions a small fraction of a cylinder of air at the same tension.

If a number of small compressors be connected with one shaft by cranks, at such angles as to divide the circumference equally, the loss of power would be reduced, or the percentage of useful effect would be increased.

Suppose, for the sake of illustration, that there were ten compressors connected with one shaft, and that it was proposed to compress the air to ten atmospheres There would be ten discharges into the receiver at each revolution, each discharge being one-tenth of a cylinder, and the sum of the whole equal to one full cylinder at the proposed maximum tension.

The power exerted in effecting the compression in each cylinder would be in proportion to the mean pressure throughout the stroke, if the air cut off at one-tenth were allowed to expand, which is 3.302; and if the air was not used expansively the theoretical loss without allowance for friction would be as 3.3 to 1, and with friction fully as 5 to 1.

But the air can be and is used expansively, and the simple device of a fly-wheel, by which momentum can be stored up and maintain uniformity during a revolution, secures equally favorable results with a small as with a large number of compressors connected with a shaft. There is no reason whatever to question the results claimed for the compressors manufactured at the Delamater works, and used on the Second Avenue Railroad, of 50 horse-power of compressed air, capable of being fully utilized for every 100 horse-power expended in the engine which works the compressors.

But it will be said there is still a loss of one-half as compared with steam applied directly. The answer is, not in cost of power; and in this fact is found the key to the solution of the problem.

The minimum of weight is essential in a locomotive engine. Heavy apparatus for securing economy of fuel cannot by any possibility be applied to it. Compound and condensing engines are entirely inadmissible on wheels of small motors adapted to street service, but all the known economies in engines, regardless of weight, can be introduced in stationary plant, and Corliss, Delamater and others, now secure as an ordinary result a duty of one horse-power from $2\frac{1}{2}$ pounds of coal.

At the Holly Works at Lockport, which claim an exceptionally high average duty, the daily evaporation is nine pounds of water to one pound of coal under 25 pounds pressure, or seven pounds of coal to one cubic foot of water evaporated; and in small boilers, such as are used for heating purposes, the average evaporation under ten pounds pressure is only four pounds of water per one pound of coal, or 15.7 pounds of coal per cubic foot of water evaporated.

With no very reliable data to determine the consumption of coal and evaporation of water in ordinary street motors, it will, no doubt, be greatly in their favor to credit them with developing a horse-power with ten pounds of coal; and the conclusion, therefore, is that although one-half the power of the stationary engine is lost in compressing air, yet the economy of fuel can be made so great that a given amount of power in compressed air is secured at one-half the cost of the direct application of steam to street motors.

But this is not all. By the simple device of heating the air by passing it through a tank of water, it has been clearly demonstrated as the result of constant practice in Paris, confirmed by recent experiments on the Second Avenue Railroad, that capacity for work is doubled, or the gain 100 per cent., making the economy of power as compared with the direct application of steam to street motors, measured as it should be, by coal consumed, four to one in favor of compressed air.

Air is compressed into the car reservoirs under a pressure of 350 pounds per square inch, or 24 atmospheres, nearly.

It is not applied directly to the motor cylinders at this pressure, experience having shown that the best practical results are secured at 16 atmospheres, about 240 pounds.

But the air is not applied cold; it is admitted to a tank of water placed on the front platform of the car, containing 5 cubic feet of water, drawn from a stationary boiler, under 80 pounds pressure and having a temperature of 328°.

If air is admitted to the tank at 60°, and leaves it at 328°, the increase of temperature will be (328—60) 268°.

To raise one pound of water from 32° to 212°, or 180°, requires as much heat as would raise 4.27 pounds of air through the same range. The specific heat of air as compared with water being as 0.2377 to 1, one pound of air increases in volume by heat from 12.387 cubic feet at 32° to 19.323 cubic feet at 328° = 6.936 cubic feet increase.

The volume of air at 24 atmospheres being 1, the volume at 16 atmospheres would be 1.5. If the volume of air at 32° be 1, the volume at 60° will be 1.061, and at 328° = 1.59. It appears, therefore, that in heating a given quantity of dry air to 328°, it will be increased in volume under constant pressure over 50 per cent.

This expansion is due simply to *dry* air; when moisture is present to the point of saturation the pressures are greatly increased.

If the air at 30° be taken as unity, dry air at 212° will occupy a volume of 1.375, and saturated air at the same temperature 2.672, or about double.

Conceding that only a small part of the theoretical expansion can be realized in practice, as the air when expanded in the motor cylinders is cooled very rapidly and there are other losses, there is still a wide margin to justify the claim of double power from heating the air. This declaration was fully sustained by actual work on the Second Avenue Railroad, where double runs of $6\frac{1}{2}$ miles had been accomplished with the same expenditure of moist and heated air as single runs of $3\frac{1}{4}$ miles with

dry air. The inevitable conclusion that results therefrom is that the power secured and utilized in air compressed with the best engines and compressors now in use costs, as compared with ordinary steam street motors, only one-fourth as much per horse-power measured by the coal actually consumed.

The air is not admitted to the motor cylinder at 350 pounds pressure, but at a much lower pressure, so that after passing the tanks and becoming heated and charged with vapor, it enters the cylinders at 250 pounds, requiring but a comparatively small volume of the dry air from the reservoirs to do the work.

This uniformity of pressure is secured by means of a reducing valve placed in the pipe, which acts automatically until the pressure is reduced below the pressure of admission. When the air has become so exhausted as to fall below this pressure, the reducing valve remains fully open.

If the water should be cooled down 100 degrees, the power of the heated air would be reduced, but would still retain great efficiency.

It can, therefore, readily be understood that a very important gain results from heating the air, and the economy of the arrangement is so great that it should never be omitted. The use of a small petroleum lamp to retain a high temperature in the water would add to the efficiency.

Cost of Heating the Air per Mile.

To raise 5 cubic feet of water from 212° to 328° requires, as we have seen, 36,192 units, or 1251 units per mile. Allowing 8000 units of heat per pound of coal consumed, the coal required to heat the 5 cubic feet of water would be 36,192 8000 = 4.5 pounds, at a cost of one cent, and this is less than average duty.

It would seem from the result of this calculation that fully 100 per cent. had been added to the power of the engine and to the miles run, at a cost of one cent in coal for heating the water.

How many Miles will the Pneumatic Motor Run?

The air reservoirs contain 160 cubic feet at 24 atmospheres. The equivalent at one atmosphere is 3840 cubic feet. Allowing one-third to be retained as reserve, there will be left to be utilized 2560 cubic feet. But in consequence of vapor and expansion by heat, this quantity is practically equivalent to 5120 cubic feet at the escaping tension. The number of cubic feet of air and vapor expended per mile run has already been ascertained to be 720 cubic feet; and 5120 ÷ 720 = 7.1 miles nearly, still leaving a reserve of one-third.

But it has been found that the actual performance exceeds this theoretical limit, and that starting with 350 pounds pressure, 9⅜ miles have been run with a reserve of 85 pounds. How can this be accounted for? Simply by the fact that the estimate of 7.1 miles was based on the supposition that a cylinder of mixed air and vapor at atmospheric tension was expended at each stroke. If nearly 50 per cent. more duty was actually secured, it proves that *less* than a cylinder of air and vapor did the work.

But, it may be asked, How is this possible? How can expansion be carried beyond atmospheric tension without creating a vacuum, and losing power by working against back pressure? This question was asked of Mr. Hardie, and the explanation brought to light another beautiful feature of this motor. There are valves called suction-valves in the exhaust passages, and whenever the tension of air in the cylinder falls below that of the atmosphere, these valves open and permit the stroke to be completed without back pressure, so that it is not necessary to use more air than will overcome the resistances, and this may vary from a full cylinder to a very small fraction, or between limits as extreme as one to thirty.

Increased Power from Motor Cylinders Acting as Air Pumps.

The motor cylinders are so arranged that in descending steep grades they act as air pumps, and at the same time as brakes, by which means it is found, as stated by the company's engineer, Mr. Hardie, that in running down grade on the Second Avenue Railroad, pumping back against a pressure of 200 pounds in the receiver, the pressure was increased 7 pounds in a distance of 0.4 mile. As it requires 360 cubic feet to run one mile, 0.4 mile would require 144 cubic feet.

If the pressure were increased 7 pounds in a receiver containing 160 cubic feet at 200 pounds, the air pumped back would have been 5.3 cubic feet at 200 pounds in 0.4 of a mile, equal to 69 cubic feet at atmospheric tension, which is about half the amount of air that would have been expended in running an equal distance with the aid of the heat on a level, with a consumption of one cylinder of air at each stroke, but with actual results 50 per cent. greater.

To appreciate the importance of this result, it must be observed that not only is all the air saved in running down hill and not a particle used, but half as much or more as would have been expended with the aid of heat and vapor upon a level is pumped back again, and at the same time the action of pumping back acts as a most efficient brake, the efficacy of which is spoken of by the intelligent mechanical engineer of the Delamater Works in terms of the highest commendation.

This is certainly a most extraordinary result, and so large a percentage of gain is only possible in consequence of the great expansion in the motor cylinders. The air and vapor escape at the tension of the atmosphere, without the noise which attends the escape of high-pressure steam. When the air at atmospheric tension is pumped back again, it can readily be perceived that a certain percentage of the power expended will be restored, since only half a cylinder of air or less is required to do the work at each stroke.

Such a contrivance can only be characterized as admirable, and, it will be perceived, adds another considerable percentage to gain in coal as compared with steam motors.

When a locomotive engine shall, while running, be able to manufacture coal and store it in the tender, it will then be able to rival this performance of the pneumatic motor.

It has been shown that at atmospheric tension the contents of the motor cylinder are just one cubic foot for each revolution of the car wheels and that there are 720 revolutions per mile. There should be pumped back therefore 720 cubic feet if the inclination were steep enough to employ full power, which is found by computation to be 198 feet per mile, and when heated, saturated, and expanded, this air should run the car two miles or more, instead of one. In other words, while running down hill one mile, on a grade of 198 feet, the motor theoretically might store up enough to run it two miles on a level; and recent experiments have shown that 50 per cent. may be added to this estimate.

Heat and Cold by Compression and Expansion.

In some forms of pneumatic apparatus much inconvenience has been experienced from the heat liberated in compression, and again from the intense cold resulting from expansion, which deposited ice in the cylinders and ports when moisture was present, as it always is in air in its ordinary condition. It has been stated by writers on pneumatics that one pound of air at one atmosphere and at 60° compressed to two atmospheres is heated 116°, and the units of heat liberated per pound are $0.238 \times 116 = 27.6$ units.

Conversely the expansion of air causes an absorption of heat or production of cold to a corresponding extent.

The compressors constructed at the Delamater Works, in New York, secure comparative exemption from the inconvenience both of heat and cold. The apparatus now in actual use on the Second Avenue Railroad consists of an engine with two steam cylinders 12 inches diameter and 36 inches stroke, operating two double-acting compressors of same stroke, one of which has a diameter of 13 inches and the other a diameter of $6\frac{1}{2}$ inches.

The number of strokes per minute in charging a car are 76 at the commencement, and 70 at the end; the difference being caused by the difference in work to be performed.

The fly-wheel weighs about 4 tons, with a diameter of about 10 feet.

The air cylinders are jacketed, and a current of cold water circulates around them continually.

The air compressed in the first compressor to about 5 atmospheres, passes into a tank of water in which the water is kept cool, and thence into the second compressor, where it is reduced in volume one-fifth a second time, making one-twenty-fifth of its original volume.

The water-tanks perform a most important office, not only in cooling the air, but in drying it also.

The explanation of this apparent inconsistency is simple.

Ordinary atmospheric air contains more or less water, which on reduction of temperature below the dew-point is deposited to a certain extent on cold surfaces.

In compressing 25 cubic feet of air into one, and cooling it with water, it is estimated that twenty-four parts out of twenty-five of the water will be absorbed and removed.

When this dry air is again expanded by being utilized in the motor, it cannot deposit ice, because there is so little contained water to form ice, and hence the fact, which it is said has excited great surprise amongst observers, that no frost whatever was formed except on the outside of the pipe from the condensation of outside moisture.

Mr. Hardie stated that when the pressure ran low and the temperature of the tanks fell below 100° frost began to be formed. This is precisely as should be expected. If air, in being compressed to one-half its volume, liberates 116 degrees of heat, it must absorb an equal amount in expanding, and if the water has cooled so low as not to furnish sufficient heat to compensate for it, the moisture taken from the water-tank must form frost to some extent.

A suggestion may here be offered in regard to the future possibilities of compressed air. Why can it not be compressed to high tensions by cheap power, transmitted for considerable distances through pipes, and used expansively in compound engines with heater, without the annoyance and risk of large boilers and coal consumption on the premises where the power is utilized? There is no reason to apprehend danger from this increase of pressure. The air receivers, unlike steam boilers, never deteriorate; the air being perfectly dry, and the receivers coated internally, there can be no rust: and if pressure is increased, the thickness of material can be increased also, and the factor of safety remain the same. Any defect of material or workmanship would be revealed by proper tests; and if a rupture should occur, there would be only

an escape of cold air—no steam and no fragments of iron. A cylinder, fully charged, was ruptured in France purposely by the fall of a heavy weight. The air escaped simply with a hissing sound; no fragments were projected as in explosions of steam boilers, and cold, not heat, resulted from the expansion.*

What Grades can the Pneumatic Motor Overcome, and What Loads can it Carry?

These are pertinent questions, and can be readily answered. Ordinary locomotives are so proportioned in their boiler and cylinder capacity as to be able to slip their wheels on a dry rail if the engine should be chained fast, so that it could not advance upon the track.

In that case the adhesion, which is, at a maximum, about one-fifth of the weight upon the drivers, measures the power of the engine, and not the pressure in the cylinders. The power varies, and is greatly reduced in bad conditions of the track.

Power of Motor Cylinders.—Assume that the air is used under 16 atmospheres, cut off at one-sixteenth, and expanded to fill a cylinder at atmospheric tension, giving mean pressure at 0.236. The initial pressure being 16 atmospheres, the mean pressure is $16 \times 0.236 = 3.776$ atmospheres, and $3.776 \times 15 = 56.64$ pounds per square inch. The diameter being $6\frac{1}{2}$ inches, the area is 33.18, and the piston pressure $33.18 \times 56.64 = 1879$ pounds. If the air should be cut off at $\frac{1}{8}$, instead of $\frac{1}{16}$, the mean pressure would be 6.158, and the crank pressure 3064.

There are 2 cylinders, cranks at right angles, one at full stroke when the other is on its centre. The weight of the car loaded is 8 tons. There are four wheels connected. Weight on drivers 16,000, adhesion one-fifth $= 3200$ pounds. The radius of the wheel is 14 inches, and of the crank $6\frac{1}{2}$ inches, then $3200 \times \frac{14}{6.5} = 6880$ pounds to be exerted on the crank, not allowing for friction of machinery, if it be required to slip the wheels on a dry rail. Or, stated in other terms, the power of 1879 pounds at the crank is equivalent to 871 at the rail, and 3064 at crank to 1422 at rail.

The power of the motor cylinders with ordinary consumption of air is therefore insufficient to slip the wheels on a dry rail, but with street motors so large an amount of cylinder power as would be required for that purpose is unnecessary; owing to the frequent bad condition of the track, a large surplus of adhesion is required. The cylinder power can be increased four-fold by admitting a full cylinder of air; but this would be objectionable, as causing waste of air and noise from exhaust, except in overcoming great resistances of short duration, as in pulling the motor over cobble-stones when derailed.

With a small motor of 6 tons the adhesion would be reduced to 2400 lbs., and the crank pressure required to slip the wheels to 5160 lbs. The adhesion in ordinary conditions of the rail is therefore, as it should be, in excess of the cylinder power, and the wheels can slip only in consequence of ice and snow. It remains to determine the power for propulsion on a straight and level track and the power required on grades.

The traction of ordinary railroad trains is 9.2 pounds per ton on a straight and level road, based on the regular business of the Pennsylvania Railroad; but with a street motor it is said to require about 25 pounds per ton, eight tons require 200 pounds, and this resistance acting on a lever of 14 inches from the axle, while the propelling power acts with $6\frac{1}{2}$ inches, will increase the power on the crank to $200 \times \frac{14}{6.5} = 430$ pounds.

As the power on the crank with the 8 ton motor is 1879 lbs., it would be sufficient to move 4 such cars, or 32 tons, on a straight and level road, not allowing for friction of machinery and losses in transmission of power from the crank, if, as has been stated, the traction does not exceed 25 pounds per ton, upon which this estimate is based. It was found that when dry air was used and the machinery was cold, the pressure of the air by gauge indications being 20 lbs., it required the full head to propel the car, while, where warm air was used, the car moved when the gauge indicated considerably less pressure.

Twenty pounds pressure is $1\frac{1}{3}$ atmospheres. The average mean working pressure is 3.776 atmospheres. Twenty pounds produces 625 lbs. crank pressure, or 300 at rail. and if this amount was required to overcome friction and move the motor, it would be equivalent to $37\frac{1}{2}$ pounds per ton, instead of 25 pounds, and absorb 50 per cent. more power than has been allowed; but it is stated that there was a back pressure at the time of several pounds per square inch, in consequence of the small size of the exhaust ports, which would cover a considerable part of this difference. It is possible, therefore, that, with the air heated, the traction may not exceed 25 pounds per ton; but it would be well to test both the traction of the motors and of ordinary cars by a dynamometer.

Grades.

It has been shown that if air is admitted into the working cylinder at a pressure of 16 atmospheres, cut off at one-sixteenth of the stroke and expanded to atmospheric tension, the mean pressure on the crank would be 1879 pounds and the equivalent to overcome resistance at the rail 871 pounds, capable of moving on a straight and level road, if all could be utilized, 4 cars of 8 tons with traction of 25 pounds per ton, and certainly 2 cars.

* This was written in 1879. At the present time, 1893, more than 25,000 horse-power are employed in this way in Paris alone.

Also if the air should be cut off at $\frac{1}{8}$, the mean crank pressure would be 3064 pounds and the equivalent at the rail 1422 pounds, capable of moving 4 such cars upon a level. As the angle of friction with traction of 25 lbs. per ton is 66 feet to the mile, the eight ton motor should be able to haul twice its own weight on a grade of 66 feet or 2 cars, on a grade of 132 feet 1 car; but 2 cars could be hauled by increasing the amount of air and cutting off say one-sixth, instead of one-eighth.

The eight ton motor without extra cars attached should be able to overcome the steepest grades usually found on horse railroads. The steepest grade on the Second Avenue Railroad is said to be 230 feet to the mile, or one in twenty-three. The power with a full cylinder of air would be about 8 times the average power expended in working, and consequently the reserve is large enough to overcome great resistances of limited duration.

Small Motors of 5 Tons with Cars Attached.

It would be a most serious disadvantage if the general introduction of pneumatic motors should require the abandonment of the old plant. Fortunately such abandonment is not only unnecessary, but the best possible system for the economical operation of a line and for the accommodation of the public consists in the use of small motors, or of combination car and motor capable of carrying from one to three additional cars in a train under one conductor, at hours when the travel requires it.

Suburban residents desire frequently to make social visits or to attend lectures or places of amusement in the neighboring cities, and can testify to the discomfort, not to say danger, of riding home late at night with one foot on the platform and the other in space.

The ordinary horse car, loaded, weighs about five tons, the motor would weigh about the same, or with six tons would admit a large increase of reservoir capacity; there would then be no pretext for objection on the ground of injury to track. It could run with one car in the middle of the day, and morning and evening with 2 or 3 under one conductor. It could make the trip in half the time, certainly in two-thirds, of the horse-car and take the place of horses, the sale of which would nearly or quite pay for the motor, so that there would be but little, if any, increase of capital for street motors, and nothing except for engines and compressors at the station.

The small motors, weighing 6 tons, would have the same cylinder power as the 8-ton motors previously described, which gives 871 or 1422 pounds at the rail, as the air is cut off at $\frac{1}{16}$ or $\frac{1}{8}$ of the stroke. The adhesion with dry rail is 2500 lbs., and the traction of the motor at 25 lbs. per ton $6 \times 25 = 150$ lbs.

If these small motors should be used to haul ordinary horse-cars, it becomes necessary, in estimating the performance of the motor, to know the traction of such cars. For obvious reasons this traction must be less per ton than that of the motor, and yet more than that of ordinary railroad cars, which is 9 pounds per ton. Probably 15 pounds per ton would be a full allowance for the traction of ordinary horse railroad cars, and a train of one 6-ton motor and two ordinary cars of 5 tons each, loaded, would make the weight of the train 16 tons, and the traction 300 pounds—an average for the train of 18.8 pounds per ton. And 18.8 pounds per ton traction would give the angle of friction at which the train would descend by gravity $= 44\frac{1}{2}$ feet to the mile.

The train of one small motor and two cars could ascend grades of 178 feet to the mile, and with one car grades of 240 feet to the mile, and steeper grades could be overcome by using more air.*

The separate motor, not intended to carry passengers, except, perhaps, on top, would permit an increase of reservoir capacity from 160 to 225 cubic feet; and if reservoirs be placed also under the seats of each car, the capacity of a two-car train with motor would be extended to 325 cubic feet, or doubled, and the run to 12 miles. If, in addition, in speculating upon the possibilities of the future, the reservoir pressure should be increased to 500 pounds, instead of 350, the run would be extended 43 per cent., or to 17 miles, and with one car attached to motor instead of two, still further. For working elevated railroads, as a substitute for steam, the pneumatic motor is the perfection of a propelling power. The motor itself could be filled with air reservoirs, giving, with the addition of reservoirs under the seats of the cars, almost unlimited capacity, and there is no run within suburban limits that would be beyond the power of the motor, with a single station in the middle of the road to reinforce the pressure. The cost of fuel would be reduced fully 66 per cent., and noise, dust, steam, and sparks from motor avoided.

If a motor should run off the track, it has power to run itself on the street pavements, and can be readily replaced by the aid of crowbars. If the machinery should become deranged, another motor could push it, and by a simple hose attachment the air in the disabled engine could work the machinery of the helper.

* Since the above was written further experiments have shown that the increased consumption of air by attaching horse-cars to the motor is about the amount that could be supplied by reservoirs under the seats, and, consequently, that the distance run need not be diminished by attaching additional cars if so provided.

With cylinders on motor $6\frac{1}{2}$ inches diameter and 13 inches stroke, pressure of air 16 atmospheres, cut off at one sixteenth of stroke, giving average pressure 56.64 lbs. per square inch, and speed of motor six miles per hour, the horse-power applied to pistons will be found to be 17.7, or, if the speed is four miles per hour, 11.8 horse-power.

Area of piston 33.18 square inches. Travel of each piston 22 inches to each revolution. 720 revolutions per mile = 3120 feet for both pistons per mile.

$3120 \times 33.18 \times 56.64 = 5{,}862{,}480$ foot-pounds per mile = 586,248 foot-pounds per minute, and $586{,}248 \div 33{,}000 = 17.7$ horse-power.

This assumes that the air operates upon the piston to the full limit of the stroke, but with less resistance much less air is used, and the horse-power will be reduced; on the other hand, there may be occasions when a temporary increase becomes necessary. By letting in a full pressure of air more than three times the normal pressure can be applied immediately.

A few minor points in favor of the motor will be stated. Skilled engineers are not required to run them; a man of ordinary intelligence can learn to run these motors in a single trip. What is a most remarkable and beautiful feature of the contrivance is that a driver, however ignorant or careless he may be, cannot fail to use exactly the proper amount of air for the resistance to be overcome, and cannot waste it. If he admits too little, the car slackens speed or stops; if too much, he must apply the brake. All is done by the movement of a lever, back or forward; no other brake is needed, and the motion of the car is a perfect governor.

Another advantage of the motors is that the view of the track is unobstructed and can be seen from the platform on which the driver sits, while horses obstruct the view of the track for 30 feet.

On a level track the car can be stopped within its length when running at a speed of 12 miles per hour, and on grades in a time longer or shorter in proportion. The brake can never be out of order so long as the car has the ability to move at all. The brake consists in a full or partial reversion by moving a lever.

If the lever should get out of order, which is scarcely within the bounds of possibility, the car could not move at all, therefore the brake cannot fail. It was noticed also in running along the Second Avenue Railroad on the motor that horses on the opposite track meeting the motor would sometimes shy, but other horses not on the track did not notice it. The car horses would, no doubt, soon become accustomed to the motor, but as its general use would supersede horses altogether, this fact is of little consequence.

OBJECTIONS.

A criticism of the motor has been made by a mechanical engineer of some prominence, which can only be accounted for on the supposition that the letter which recites the objections was written without consideration.

It is desirable, however, to have objections stated; when they can be shown to be groundless they serve to inspire and increase confidence.

The objections were:

1. The air car requires 50 horse-power in compressors to keep it in operation.

True! But if dry air be used the same engine will charge 7 cars per hour, and if moist and heated air be used 14 cars, if the run should not be increased and only half the air should be required, which is only 4 horse-power to a car, and each horse-power costs in coal consumed one-fourth to one-third as much as in a street motor.

Second objection. The cost of repairs for the steam cars would be less than for the air car.

Ans. No reasons are given, and the fallacy of the assertion is self-evident. There is no fire-box to burn out, and no boiler to rust, burn out, or explode. The reservoirs, filled with air absolutely dry, are as nearly imperishable as anything on this mundane sphere can be The parts liable to wear by friction are the same as on other engines, neither more nor less expensive to repair, but the heaviest expenses of fire-box, boilers, and flues are all saved.

Third objection. The air car is not so reliable as a steam car, as it has not the same surplus for emergencies.

Ans. Why not? A surplus is provided of 33 per cent. Does a locomotive finish its trip with as much reserve power in coal and water in its tender? Besides, all the cars of a train can have air cylinders under the seats, the whole of which can be held in reserve.

The above are the only objections advanced.

LOCATION OF POWER PLANT.

Considerations of economy would lead to the location of the power plant at or near the middle of the section of the road to be operated, for the reason that the power could be readily renewed by a simple hose attachment while passing the central station, whereas if located at one end a supply for a run of double the length would be required; but it may be, and in a majority of cases probably will be, found most economical to locate the compressed plant back of the main thoroughfare, where land is of comparatively little value, and transmit the compressed air through pipes to any number of reservoirs conveniently located along the route.

These reservoirs would occupy but little space, and would not require a front location upon the thorough-

fare traversed by the cars. They could be placed one hundred feet or more in the rear, or even under ground, and from them strong wrought-iron pipes could lead to the track, where an air plug with hose attachments covered by a manhole plate would afford facilities for replenishing the air charge of the motors at any intervals however short that might be considered desirable. Underground pipes could be carried to the car sheds to supply motors with full charges while standing on the tracks.

As all the reservoirs upon the line would be connected with each other, and with the central plant the pressure would have a constant tendency to equalize itself throughout the whole system, and a large reservoir capacity thus created would be of great advantage in insuring an ample supply of air under nearly uniform pressure.

Oil is frequently transmitted in pipe lines under a pressure of 1500 pounds per square inch, so that a pressure of even 600 pounds would not require pipes of extraordinary thickness.

In the transmission of elastic fluids through pipes for long distances there is a loss of power due to friction dependent upon the length and diameter of the pipe, but more upon the velocity of transmission. This subject was very fully investigated by the writer in 1879 in connection with the Holly system for the transmission of steam for heat and power.

If, for the present, it be assumed that air is compressed to 40 atmospheres at a central point, and transmitted by pipes of six inches diameter for utilization in distant reservoirs and in quantity sufficient to charge one car cylinder of 160 cubic feet capacity per minute, the initial velocity of the air in the pipe would be twelve feet per second as a maximum, and the loss of head by friction, based on the tables deduced from experiments at the Mt. Cenis Tunnel, would be but 1.83 pounds in a distance of one mile, assuming that the car cylinders should be returned entirely empty and require 160 cubic feet as the initial pressure.

But in the trips on the Second Avenue Railroad the cars returned to the station with one-third of their charge remaining, or with 8 atmospheres, after expending 16 atmospheres in the run; consequently a charge of 40 atmospheres would have permitted just double the distance to have been operated with a single charge, which would be 18 miles.

One car per minute could be required on any city line only at the hours of maximum business, and even at such hours, if the cars returned with partial charges, the quantity of air required for re-charging would be less than the maximum, the velocity of transmission would be reduced, and the loss by friction, which is as the square of the velocity, would be reduced also. Instead of dispatching one car per minute, the same capacity can be more economically afforded by one motor car in 2 minutes with one trailer, and still more with 2 or 3.

It would seem to be practicable, therefore, on extended lines to locate compressor plants at intervals of 20 or 25 miles, and transmit power in pipes to intermediate stations 10 or 12 miles distant, with additional intermediate reservoirs at stated intervals to be used in case of accident, such reservoirs consisting simply of a number of small cylinders of steel two feet, more or less, in diameter, connected with each other by pipes. The cylinders of small diameter would be necessary to secure strength.

Whether the pneumatic system could be extended to supersede steam motors on ordinary railroads is a question that can be reserved for future consideration. It may be observed, however, that the traction on straight and level steam railroads is only 9 pounds per ton for the train, while on ordinary street railroads it has been estimated for the motor at 25 pounds. Also, that in passenger cars reservoirs of air cylinders can be placed below the seats, and the floor of the car may rest upon two longitudinal cylinders supporting in the middle of the car a number of transverse cylinders. The frame could be of hollow pipes, and thus a very considerable reservoir capacity could be provided in each car. A tender filled with air reservoirs could take the place of the ordinary tender with coal and water. How far such a train could be made to run with ordinary cars without reinforcement of power, and what the cost of power as compared with steam, would be interesting inquiries, for the determination of which all the necessary data have not yet been fully presented, and it is moreover foreign to the present inquiry. There can be no doubt, however, and conclusive evidence can be and has been presented, that for street, elevated, and underground railroads steam cannot favorably compare with air, either in economy, convenience, or freedom from dirt, smoke, noise, and other nuisances. In fact, it can justly be claimed that it fulfils every condition that could possibly be desired, and is free from any objection that can be urged.

Record of Direct Experiments with the Hardie Motor.

For several days previous to March 12, 1879, experiments were made with the motor on the Second Avenue Railroad, the results of which it is proper to note.

March 9th, started from depot at 127th Street, and made three round trips, with the following record :—

1st trip started with pressure	360	pounds.
Consumed	95	"
Returned with	265	"
2d trip started with	265	"
Consumed	95	"
Returned with	170	"
3d trip started with	170	"
Consumed	75	"
Returned with	95	"

This result was so remarkable, that the President of the Company, Mr. F. Henriques, requested the writer to superintend some further experiments, to ascertain if increased duty would be secured by running at reduced pressures. Accordingly, on March 10th, three more trips were made, with the following record :—

1st trip started with	360 pounds.
Temperature of water	324°
Mean working pressure while running .	120 pounds.
Water absorbed	31 "
Pressure on return	290 "
Consumed	70 "
2d trip started with	286 pounds.
Mean working pressure	120 "
Consumed water	11.3 "
Temperature of water on return . .	198°
Pressure at end of trip	195 pounds.
Consumed	91 "
3d trip started with	195 pounds.
Mean working pressure until pressure fell below	120 "
Water absorbed	19.8 "
Temperature on return	180°
Pressure at end of trip	95 pounds.
Consumed	100 "

The comparison of these two tests exhibits very remarkable results.

The total consumption of air in the three round trips, starting with 360 pounds and finishing with 95, was 265 pounds, or an average of 88.33 each trip. The last trip of the first series was run with 75 pounds. This fact it is difficult to explain, as the water was certainly much cooler than at the start, and it could not have contributed so large a proportion of vapor.

In the first run of the second series the air consumed was 70 pounds pressure, equivalent to 747 cubic feet, or $57\frac{1}{2}$ pounds at atmospheric tension, and this air absorbed the very extraordinary amount of 31 pounds of water, or more than half a pound of water for each pound of air, which is double the average consumption and four times the capacity of ordinary air for moisture.

It will be observed, also, that a great reduction of temperature from 324° to 190° or 126° was found in the two runs.

The large quantity of vapor and heat abstracted from the water in the first run will fully and satisfactorily account for the small quantity of air consumed, and would serve to indicate the possibility of increasing the distance run by burning gas or petroleum to replace the heat which the air absorbs.

In the last run of the second series 100 pounds were consumed. This was to have been expected, as the water at the end of the run was 32° below the boiling-point, and water instead of steam was probably carried out.

On Tuesday, March 11th, further experiments were made to determine the effect of attaching additional cars to the motor. The following is the record taken by Mr. Harley :—

1st trip started from 127th street, with .	300 pounds.
At depot, 97th Street, air pressure .	250 "
Consumed in half trip	50 "
Coupled on 2 ordinary street cars, pressure at end of trip, 127th Street .	170 "
Consumed with the 2 cars and motor .	80 "
Temperature of water	205°
2d trip, started with	335 pounds.
Run at mean pressure	150 "
Cars in tow	2
Pressure at 97th Street	275 pounds.
Consumed	60 "
Water used	14.2 "
Reduced pressure in heater to . .	130 "
2d trip return, 2 cars in tow, started from 97th Street, pressure	275 pounds.
Pressure at 127th Street	190 "
Consumed pressure	85 "
Water used	14.2 "
3d trip, heated water again, 2 cars, started from 127th Street with a pressure of	330 pounds.
At 97th Street, pressure	265 "
Consumed	65 "
Water used	16 "
Return, no cars in tow, started from 97th Street	250 "
At 127th Street	200 "
Consumed	50 "
Water used	11 "

OBSERVATIONS.

It appears that the two *up* trips consumed 80 and 85 pounds of pressure, and the two *down* trips 60 and 65 pounds, and the up trips required 33 per cent. more than the down trips. This may be due to the very bad condition of the up track. The average round trip required 145 pounds with two cars attached to motor, as against 90 pounds with motor alone, an increase of 60 per cent., or 30 per cent. for each car hauled. The two cars probably weighed as much as the motor, and, if so, the traction of the cars would be 15 pounds per ton, assuming the motor at 25.

The data furnished by observations on the motor will serve to indicate the loss of power and of work in transmission from the piston to the rail. Starting at 350 pounds pressure, the run of $9\frac{3}{4}$ miles was made with 270 pounds pressure, or 90 pounds per average run, or 298 cubic feet of air, at atmospheric density, per mile. Assuming for the present that the effect of heating and moistening the air is chiefly to compensate for the reduced temperature in expanding, and to secure the full benefit of isothermal expansion, the foot-pounds of work per mile will be computed on this basis.

The volume required per mile to fill the capacity of the working cylinders is 720 cubic feet; the 298 cubic feet therefore filling 40 per cent. of the cylinder capacity, leaving 60 per cent. to be replaced by air from the ex-

haust passages, by the opening of the suction valves.

If used under an average pressure of 170 pounds = 11.33 atmospheres indicated, or 12.33 atmospheres actual, the atmospheric pressure would be reached in $13 \times 0.4 = 5.2$ inches of stroke in cylinders, and the mean piston pressure during the 5.2-inch stroke would be 1732 pounds.

As there are 4 cylinder discharges to each revolution, and 720 revolutions to a mile, the travel of piston per mile run under pressure will be $720 \times 4 \times 5.2 = 14{,}976$ inches = 1250 feet, and $1250 \times 1732 = 2{,}165{,}000$ foot-pounds of work done at piston per mile of actual run. If now it requires a tractive force of 25 pounds per ton on a level road to move the motor, and the weight be 8 tons, then $8 \times 25 \times 5280 = 1{,}056{,}000$ foot-pounds per mile, which, if the road was level, would represent the actual work utilized from an expenditure of 2,165,000 foot-pounds upon the piston, which is 50 per cent. nearly.

It would appear, therefore, that only half the power applied to the piston is actually utilized in propulsion on the track, and the balance must be expended in overcoming friction of motor and other resistances and losses. The power required to move the motor, if applied externally, and also the traction of the ordinary horse-cars, is not known, and should be determined.

The computation of average run has been based on an expansion of 12, and reaching atmospheric tension at 0.4 of the length of the cylinder, using only one-thirtieth part of a cylinder of air at each stroke. If a full cylinder of air should be used, the power on the piston would be increased nearly nine times, but the consumption of air thirty times.

This great reserve of power over the average for ordinary work is an advantage of no small importance. The reserve of power can be drawn upon to overcome great resistances, if of short duration.

As an illustration of this fact, and since the above paragraph was written, Mr. James, who was associate engineer with Mr. Hardie, states that on one occasion the motor got off the track at a sharp curve and switch at the 127th Street depot; a ditch had been dug for gas pipes and filled in, but not paved. The hind wheels sunk in the ditch until the frame of the motor rested on the pavement. A high pressure was let on and the machine pulled itself out without further assistance.

This power of overcoming great resistances of short duration is of great value.

In the consideration of the question of hot water motors, the position was taken that in the conversion of hot water into vapor or steam nearly a thousand degrees became latent, and this latent heat so rapidly cooled the remaining water from which it was abstracted that it was not possible, without the use of a fire, to restore the heat, and that the motor could not possibly run the distance claimed for it.

The observations just reported on the Hardie motor fully sustain these conclusions.

The first trip in the second series started with full tank, 5 cubic feet or 310 pounds of water, at a temperature of 324°, and used 31 lbs. water.

The second run used 11.3 lbs., and the third 19.8 lbs., in all 62.1 lbs., and the temperature in return was 180° with 248 pounds of water.

The differences there were :—

310 pounds water at	324° =	100,440 units.
248 " "	180° =	44,640 "
Units lost with 62 lbs.		55,800

But 62 lbs. water with a difference of temperature of 144° would remove only 8928 units, leaving 46,972 units to be accounted for as latent heat. This is equivalent to 758 units per pound of water evaporated.

As this is less than the amount of latent heat required for the conversion of water into steam, it follows that after the temperature of the water fell below 212°, water and not steam must have been carried over with the air.

If figures are made upon the first two runs where the temperature was maintained above or near the boiling-point, the data are: Temperature at starting, 324°; on return, 198°; loss, 126°. Water evaporated, 42.3 lbs. Units at 126° = 5330.

Weight of water at starting, 310 pounds; on return, 267.7 pounds.

Thermal units at start, $310 \times 324 =$	100,440
Thermal units on return, $267.7 \times 198 =$	53,004
Loss of thermal units . . .	47,436
Accounted for by sensible heat-units as above	5,330
Leaves unaccounted for . .	42,106

If 1000 units per pound be allowed latent for water, 42,300, the difference is therefore fully accounted for, and proves that where air is passed through hot water the water removed carries off not only the units of sensible heat due to the difference in temperature, but also cools the remaining water to the extent of 1000° for every pound of water removed.

Another important observation may here be made. In the 3 round trips of 9¾ miles the loss of heat-units in the tank was 55,800. If the heat had been maintained at 324° by means of a small naphtha or petroleum stove yielding more than 20,000 units in combustion, it is reasonable to assume that 15,000 units could be utilized, and consequently 4 pounds, costing not more than 3 cents, would supply the units for more efficient reheating at a cost of 3 mills per mile run of motor. This reheating, it will be remembered, doubles the run with a

given volume of air; in other words, 5 miles would be added to the run of the motor at a cost of 3 cents, which is a maximum cost.

Small as this is, it is still higher than Mr. Hardie's estimate for hot water drawn from stationary tanks. He allows $\frac{1}{8}$ of the coal used in compression. In this case 6 pounds of coal should furnish the 55,800 units, at a cost of one cent; but by referring to the record, it appears that where the temperature of the water was 324° at the start, the run was made with 70 pounds pressure, and could probably have been made at 65 pounds if the temperature during the run had been maintained at 324°. At this rate the air evaporated per mile would have been reduced from 300 cubic feet to 240.

Another observation on this very important subject of reheating should be made. The air was not only expanded by the heat, so as to exert a higher pressure from that cause, but there were carried over 62.1 pounds of water in the form of steam, which would be equivalent to 1700 cubic feet of air at atmospheric tension, with the additional advantage of a warm exhaust and no possibility of frost. This accession of motive power in addition to the elevation of temperature will account for the fact that double runs were secured by the simple expedient of passing the dry air through a small tank containing only 5 cubic feet of hot water.

VIII.

ECONOMICAL MODES OF COMPRESSION.

In reference to the most economical method of furnishing supplies of air to the motor tanks, Mr. E. Hill, of the Norwalk Iron Co., who has had very extended experience, gives the following information:—

There are four methods in all of charging air tanks.

First. A reservoir capacity two, three, or four times the size of the tanks and containing a pressure of air much greater than the pressure in the tank, so that when the valve between tank and stationary reservoir is opened and the pressures equalized, the resulting pressure in the tank will be the pressure desired.

Next. Stationary reservoirs charged to a pressure somewhat higher than the pressure desired in the tank and said stationary reservoirs brought in connection successively with the tank to be charged.

Third. A reservoir of very great size in comparison with the size of tank to be charged, so that for practical purposes the air can be considered as being drawn from a reservoir of infinite size.

Fourth. Direct pumping into the tank itself.

Referring to plan No. 1, we have considered that a reservoir three times the capacity of the locomotive tank is employed. This reservoir must be charged to a pressure of 53.33 atmos. in order that the pressure in reservoir and tank shall be 42 atmos. after the reservoir and tank have equalized their pressures. The duty then for a compressor will be to pump up that tank from 42 atmos. to $53\frac{1}{3}$ atmos. at each charging of the locomotive. If this work is done in one minute, it will require 2380 H. P.

Referring to plan No. 2, it will be assumed that three stationary reservoirs are used, and that each reservoir is of a size equal to the size of the tank on the locomotive. If these three reservoirs are charged to 47 atmos., and reservoir No. 1 is brought into connection with the tank of the locomotive, the pressure will equalize between the two and become $27\frac{1}{2}$ atmos. If now No. 2 tank is brought in connection, the pressure will become 37.25. If the third reservoir is now connected, the pressure will become 42.12 atmos. Therefore, the duty required of the compressor is to pump up tank No. 1 from $27\frac{1}{2}$ atmos. to 47 atmos., tank No. 2 from 37.25 to 47 atmos., and tank No. 3 from 42.12 to 47 atmos. This will require 2119 H. P. if done in one minute.

Referring to the third plan, in which the reservoir is of very great size, so that practically when the locomotive is charged there is no fall of pressure, the duty then of the compressor is to compress all of its air to 42 atmos. To supply the locomotive under these circumstances, each minute will require 1828 H. P.

The fourth plan, for direct pumping, presumes that absolutely no reservoir at all is used. Here the duty is simply to raise the pressure in the locomotive by direct pumping from eight atmos. to forty-two atmospheres. This will require 1706 H. P. if the work is done in one minute.

It will, of course, be noticed from the above comparisons that the fourth plan as regards power is by all means the one to be preferred; but it is not presumed that such a large quantity of air can be compressed so quickly and cooled so rapidly in one minute. Therefore calculation should be made, if a locomotive is to be dispatched every minute, to have a number of locomotives at the charging station at the same time, so that each of those locomotives could be under treatment from ten to fifteen minutes, in order that the air may have *time* to cool during the process of compression, but the total power will be such as to dispatch one locomotive every minute.

Answering other questions regarding the power to do the above work in $2\frac{1}{2}$, 5, and 10 minutes, it may be said that follows in inverse proportion. The above calculations are taken at a mean between isothermal and adiabatic compression, and are as near as possible what will be actually found to be the result in practice.

As regards the expense of running compressors, it is proper to state that the above calculations give the power in H. P. The expense of a H. P. is a well-settled matter according to the style of engine which is employed to produce it.

Frost from Expansion of Air.

It is a common, but very erroneous, opinion that serious difficulty is experienced in compressed-air engines from the intense cold produced by expansion and the closing of the exhaust passages by frost. No difficulty of the kind has ever been experienced in the use of the Hardie motor, even with cold air; but the practice of reheating, which should never be omitted, since it doubles the power at nominal cost, raises the temperature of the exhaust air above the freezing-point. In the tests made on the Second Avenue Railroad in 1879, it was found that, although the air from the compressor was cooled by passing it through water, there was no deposit of frost. The writer explained the fact on the theory that the capacity of air for moisture was not increased by density, and that the escaping air was too dry to deposit moisture even at a very low temperature. Mr. Hill, of Norwalk, confirms this opinion, and has given the following very satisfactory explanation :—

"Your statement regarding the water left in compressed air agrees exactly with the authorities on this question as we understand them. The density of the air does not have an appreciable effect on the amount of moisture within a given space. The temperature, however, affects it according to well-settled results. It has been observed that the higher that air pressures have been the less liability there is to freezing at the exhaust. This result is in opposition to the preconceived opinions regarding the use of compressed air. Air of 15 to 30 lbs. pressure when expanded in an engine almost uniformly gives trouble at the exhaust. Therefore it has been argued that air at very high pressure—several hundred pounds—would give a proportionate amount of trouble there, freezing because its exhaust could be expected to be so very much colder than the exhaust of air of lighter pressure; but, as I have stated above, it has been found that the air at high pressure does not give this anticipated trouble, and in fact does not give as much trouble as does air at lower pressure. The reason for this is readily explained. Air at the low pressure, when it is exhausted, will be cold enough to freeze whatever moisture there may be in it. Air at the high pressure will, of course, be cold enough on exhaust to freeze the moisture that may be in it. But to get the same power from low-pressure air as we can get from high-pressure air, we must use of the low-pressure air very many more cubic feet. As when temperatures are equal the moisture in the air depends upon the volume, it follows that for a given power when obtained from low-pressure air we have passed through our engine much more moisture, and, as it all freezes in any event, we run a greater risk of being stopped at the exhaust. Taking another case where air at 600 lbs. pressure is stored in the reservoir of a pneumatic locomotive and is then, through a reducing valve, drawn down to 100 lbs. pressure for use in the cylinders, we would find that the air at 100 lbs. pressure would be only $\frac{1}{6}$ saturated with moisture. The air at 600 lbs. pressure would be fully saturated. The moisture in one cub. ft. of 600 lbs. air being by the process of reduction distributed through six cub. ft. of 100 lbs. pressure, the result is that the air of 100 lbs. pressure is, as stated above, only $\frac{1}{6}$ saturated. Or, stating the case in another way, a cubic foot of air at 100 lbs. pressure which has been obtained from a tank holding 600 lbs. of air would contain only $\frac{1}{6}$ the moisture which would be found in a cub. ft. of air at 100 lbs. pressure, which had been obtained by compressing atmospheric air to 100 lbs. pressure.

"The above statements would all hold true without regard to the method of cooling. The question only would be, what is the temperature of the air, and has it been quiescent long enough to allow the moisture to be dropped? The statement which I have heard made, that blowing air through water dried it by reason of the affinity of the water for the moisture in the air, is, in my opinion, a lame explanation. The process dries the air simply because it cools it, and any other method of cooling would accomplish exactly the same result."

Considerable space has here been given to the subject of compressed air as a propelling power on street railroads, for the reason that writers who treat upon the subject of street motors almost invariably pass it over with a few disparaging remarks as something that has been tried and found wanting. It is really amazing to find so vast an amount of ignorance accumulated on this subject. The reasoning seems to be: Well, this thing has been tried; if it had any merit, why was it abandoned? And no trouble is taken to inquire into the merits of the motor, or the causes which prevented its general use,—causes having no connection whatever with the merit or the practicability of the invention. If the facts that have been stated will lead intelligent engineers and capitalists to investigate, there will soon be a change of public opinion upon this subject, and the best of all modes of propulsion for street service will not be cast aside for other systems far more expensive in plant and operation, and far less satisfactory in results, both to the public and to capitalists.

IX.

COST OF OPERATION OF THE COMPRESSED AIR MOTOR FOR ONE DAY—SIX MILES DOUBLE TRACK.

For the determination of this question the data can be relied upon with more confidence than in any of the other cases under consideration.

It has been demonstrated that the motor can be run with 300 cubic feet of free air per mile, and that the compressor plant to furnish this volume of air for each of 60 motors will require not more than 600 horse-power, or 10 horse-power at the central station for each motor. Each horse-power requires 2½ lbs. per hour of $3 coal, so that the coal per motor per hour will be 25 pounds, to which the equivalent of 3 pounds must be added for reheating, making 28 lbs. per hour for a run of 6 miles. The consumption per mile run will, therefore, be 4⅔ pounds, and the cost 7 mills per mile run.

This is the whole cost of fuel, not including interest and repairs, which are less than in other systems.

Cost of Plant and of Operation for the Pneumatic Motor.

Land, 22,000 square feet of ground, at $1.50	$33,000
Building	80,000
Engine, boiler, setting, etc., for 600 H. P.	30,000
Reservoirs, pipes, etc.	5,000
Cost for six miles double track	$148,000

Street Construction—One Mile, Double Track.

Track	$20,000
Paving, 9282 square yards, at $3	27,846
Total street construction	47,846
Cost for six miles	$287,076

Equipment.

75 combination cars and motors, at $3500	$262,500

Summary.

Power-house and plant	$148,000
Street construction	287,076
Equipment	262,500
Engineering, legal and miscellaneous expenses	20,000
	$717,576

Cost of Operation of Six Miles Double Track for One Day with the Pneumatic Motor.

Coal, 5760 miles run at 4⅔ pounds per mile—13½ tons, at $3 per ton	$40.50
Water, oil, and grease	6.50
Depreciation of plant and rolling-stock	78.00
60 Conductors, at $2	120.00
60 Drivers, at $1.75	105.00
Engineers and firemen at station	25.00
Car-house and other service	28.00
Repair of motors and cars	200.00
Repair of engines and compressors	15.00
Repair of track and buildings	50.00
Track cleaning, train, and shop expenses	25.00
Accidents	20.00
Legal and other expenses	10.00
General and miscellaneous expenses	50.00
	$773.00

Cost per mile . . . . 13.42 cents.
Of this amount the fuel alone costs 7 mills.

Compressed Air for Elevated Railroads.

The practicability of using compressed air instead of steam on elevated railroads and its superior economy were fully demonstrated, in 1880, on the Second Avenue Railroad, in New York.

A motor was constructed at the Baldwin Locomotive Works, upon the plans and under the immediate supervision of Robert Hardie, and was tested upon the Second Avenue Railroad; certificates of these tests by prominent officers and machinists of the road are in possession of the writer.

The section of the road upon which the experiments were conducted is 8½ miles long, and there are 22 stations in this distance. The road is undulating and circuitous; an elevation of 80 feet has to be overcome in a part of the distance, and 6 quarter-circle curves of 90 feet radius. Intervals between trains, 3 minutes.

A report by Charles W. Potter, in 1883, gives a very full account of the test of the Hardie motor on the elevated road and its economic results. An extract is here given:—

"The Hardie engine, weighing 18¾ tons, was found capable, with a single charge of air, of hauling the regulation five car trains, full of passengers (weighing approximately 60 tons, or about 78 tons including the engine), the entire distance of the road, making all regulation stops to deliver and receive passengers, accomplishing the trips in the schedule time, and with sufficient surplus of air remaining to enable it to return light to the engine depot, a distance of 5½ miles, the greater part up hill. The quantity of air expended in making these trips with trains was equal to 12,600 cubic feet at atmospheric pressure, and in returning light, 4600 cubic feet; making a total expenditure of 17,200 cubic feet. It may be mentioned that this distance is the utmost which the present steam locomotives travel without a fresh supply of water.

"The efficiency, and still more the economy, of an air locomotive increases with the magnitude of the scale on which it is constructed: and therefore, as the engine whose performances are given was built for experiments on the elevated railroad, and was necessarily limited in weight, it is clear that were it possible to increase the weight to 30 or 35 tons, as would probably be the case in an underground railway, the storage capacity for air would be increased and a proportionately longer distance would be possible with a single change.

"Moreover, the weight of the London underground trains, in proportion to the weight of the engines that draw them, is *less* than in the case of the elevated trains in New York, and, as the stations are farther apart, still better results may be expected. In fact, it is urged that in point of efficiency air engines of the Hardie type can be constructed to meet all the requirements of every

portion of an underground as well as of an elevated railway even better than steam, for the pure air discharged at each revolution will also aid in ventilation.

"The next and most important consideration is the cost, first of equipping the road, and secondly of operating it, and as in this particular it would be well to have all estimates on actual experiment, it is desirable to again revert to the results attained upon the elevated railroads in order to make a comparison with the steam engines there in use.

"As the storage reservoirs used in air locomotives are cheaper to construct than the boilers of steam locomotives, and as the machinery in the one case entails practically no more complication than in the other, it is clear that in point of first cost the balance is in favor of the compressed air locomotive; but the margin of saving is rather more than counterbalanced by the compressing plant necessary for furnishing the air. The builders of compressing machinery in the United States estimate that to furnish 12,600 cubic feet of free air (the quantity expended by the Hardie engine in a single trip) compressed to 600 pounds per square inch, which was the storage pressure adopted in the engine now under consideration, and to furnish this supply every three minutes, the amount of horse-power required is 1285, and they are willing to guarantee the correctness of this estimate, and contract for the supply of the necessary plant.

"As the locomotives used have to be supplied with air at each end of the road, this amount of power must be duplicated; hence a total is necessary of 2570 horse-power, or say roundly 2600, to operate the particular section of the road referred to. On the whole, therefore, the first cost of equipping the road might be somewhat greater for air than for steam locomotives; but this, as will be shown later, would be more than counterbalanced by the reduced cost of operating. As it requires at least 36 locomotives to carry on this traffic, at three minute intervals, including switching and relays, each locomotive would be represented by about 72 horse-power of stationary plant, and this is the maximum that would be needed, as it is only during a few hours morning and evening that the interval between trains is so short as three minutes, and as it is obviously expedient to divide up the power into, say, four complete sets at each terminus, it would only be necessary to operate the whole of it during those few hours, and thus ample opportunity would be afforded for inspection and repairs.

"Strange as it may seem at first sight, considering that the power is used second-hand, so to speak, yet a very large saving is effected in point of fuel, and it is this saving, with that of the fireman on the locomotive, that turns the balance of economy greatly in favor of compressed air. The cost of operating is computable as follows:—

"The average rate of consumption in these steam locomotives is one ton per 60 train-miles, or about 45 pounds per mile. This is necessarily high, owing to the frequent stoppages. As previously stated, 2600 horse-power will charge a locomotive with compressed air every $1\frac{1}{2}$ minutes, or 40 locomotives per hour, and each locomotive will haul a train $8\frac{1}{2}$ miles, being 340 train-miles per hour. The stationary compressing engines need not consume more than 2 lbs. of coal per horse-power per hour, or say $2\frac{1}{2}$ lbs. to make allowances and be on the safe side. Hence the consumption of fuel for 2600 H. P. will be 6500 lbs. per hour, and 6500 lbs. over 340 miles equals less than 20 lbs. per train-mile, not half the consumption of the steam locomotives, and only one-fourth the cost, as cheaper fuel may be used. Again, as the air locomotives require only one man to drive them, a considerable saving in the cost of labor is effected, even allowing for the comparatively small attendance necessary to work the stationary plant."

In the figures given by Mr. Potter, he estimated a saving of 17 pounds of coal per train-mile and 340 train-miles per hour. If this average should be maintained for only 12 hours, allowing for longer intervals at midnight and in the middle of the day, the saving of fuel would be 5780 lbs., or 2.89 tons per hour, $34\frac{1}{2}$ tons per day, and 22,592 tons per annum, costing in the tender of engine probably $5 per ton, or $112,960 per year, the interest at 5 per cent. on $2,259,200.

But this is not all. The 36 engines require firemen, and deducting 11 to offset labor at the compressor plant, there will remain 25 men at $1.75 per day. This small item amounts to $16,000 a year, the interest on $320,000 at 5 per cent.

What would be the cost of the compressor plant to furnish 12,600 cubic feet of free air in $1\frac{1}{2}$ minutes = 8400 cubic feet per minute? The compressors, boilers, and engines can all be covered by $115,000, so that the saving in firemen alone would represent nearly three times the cost of the compressor plant.

How can there be any question, therefore, as to the great superiority of compressed air over steam for the operation of city railroads, whether surface, elevated, or underground?

Why Compressed Air is Not in General Use.

If, as stated, it has been demonstrated by actual results, both on surface and elevated railroads, that compressed air furnishes a mode of propulsion far superior to steam or horse-power and at the same time far more economical, affording superior public accommodation and larger dividends to the companies, requiring no trolley wires overhead, or cables beneath the surface, with not a single objectionable feature of any description, but many in its favor, why is not the system universally

used? The question is pertinent, and the answer can be briefly given.

In 1879 public opinion was not sufficiently educated to regard this improvement with favor. Absurd as the objection then made may now appear, presidents of horse railroad companies declared that any car moving along a street without horses in front would frighten other horses even if there was no noise, and that many accidents would occur and suits for damages be instituted; that the system could not be used without stuffing the skins of dead horses and running them on a low truck in front. This was the reason given to the writer by the president of a city railroad in Philadelphia, who declined to consider the question of the advantages of a change of system, and attempts to induce others to examine into the merits of compressed air proved equally unsuccessful, so that efforts were discontinued.

When it is considered that both cable and electric roads run without horses and cause far more noise than the pneumatic engine, the objections made in 1879 appear very absurd.

But this was not the only cause of failure to secure the adoption of the improvement. Mr. Hardie unfortunately fell into the hands of irresponsible parties and parted with the control of his patents to a straw company, the collapse of which put an end to further efforts. Mr. Hardie afterwards accepted a position as superintendent of a locomotive works, and has recently filled the position of mechanical engineer of the Columbian Exposition at Chicago. The following is his own story of the causes of failure in the introduction of the pneumatic motors:—

"The proper way to have met all objections was not by discussion and argument, but by a practical demonstration. Railroad men were not satisfied with a few exhibition trips of the motors, although, as a general rule, the performance was considered very satisfactory so far as it went; but they all wanted to see a railroad operated exclusively and successfully; and until then no railroad would adopt the system. As it required capital to do this, and as the motor company had practically none, the enterprise was never carried beyond the experimental stage. It is true that this company was capitalized at $1,000,000, but that needs explanations. Those who organized the company were men of no financial standing, and the stock was all issued to them, without payment or consideration, except the expenses of organization and a few preliminary tests. In order to evade the law which required that the stock should be paid for at its full par value, a valuation of $1,000,000 was put upon some patents which one of their number held in trust; and the stock was issued to him in consideration of said $1,000,000 worth of patents: said trustee then divided the stock, as previously understood and agreed on, including a small percentage to the patentees. In order to provide 'working capital,' the stockholders assessed themselves in a percentage of their stock, which was set aside as 'treasury stock,' to be disposed of at whatever price it could be sold for. In this way some money was raised, but not enough to do any real business, and consequently nothing was done beyond making exhibition runs of the motors, and getting flourishing accounts into the newspapers, on the strength of which the individual members 'peddled' their stocks.

"Among those who bought stock was a gentleman of means, as well as culture and refinement, and strict integrity. In some way he was induced to loan the company money from time to time on its notes, and this kept it alive a while longer. Indeed it began to look as if some real business might be done after all. A compressed-air locomotive was built and tested on the elevated railroad, which succeeded in hauling their four-car trains, loaded with passengers, the whole length of the road; making all the stops to receive and deliver passengers, making the schedule time, and, in fact, doing practically everything which the steam locomotives were required to do. At the end of the trip it was found that a sufficient surplus of compressed air remained in the reservoirs to insure against possible failure; and, as will be shown later, the economy was beyond question. For some unexplained reason, however, this success was not followed up, and eventually a sudden and complete collapse was brought about by the sudden and sad death of the gentleman referred to, in whose estate the company's overdue notes were found.

"The inside workings and manipulations of this straw company, with paper capital, would make interesting reading; but I trust enough has been said in the brief space allowable here to show that it was not an organization well calculated to make a commercial success of such an undertaking, and is my explanation for the project being abandoned. Needless to say, it was a great disappointment to me. Those desiring to investigate further can be furnished with plenty of evidence as to the practical utility of the system, and the mechanical success of the experimental motors."

Notwithstanding the success of the air motor on the Second Avenue Elevated Railroad and the favorable indorsement of the officers who made the tests, the directors were not inclined to incur at that time the expense of a change of plant, and the death of the capitalist who had advanced the money for the construction of the motor caused the abandonment of further efforts. It was in fact impossible for Mr. Hardie to take another step, as he had parted with his patents for a stock consideration which proved to be worthless, and the company had hypothecated these patents, which were its only assets, for loans that they were unable to pay.

Mr. Hardie has prepared new plans with valuable improvements, the old patents have nearly all expired, and the way is open for the introduction of air motors without fear of annoyance by hostile litigation.

X.

OTHER AIR MOTORS.

THE newspapers from time to time publish notices of new motors which have a very brief existence and never pass the experimental stage.

Some of these have been misnamed compressed air motors, but the air, instead of being applied to operate a piston in a metal cylinder, is used to communicate motion to some intermediate machinery, and the action depends upon the application of principles essentially different from those that have been utilized in the compressed air motors of Hardie and Mekarski.

In one of these proposed systems a line of pipes about 6 inches in diameter was laid under ground in the middle of the track and rotated by steam, compressed air, or other power. An arm like the arm of a cable-grip car passed through a slot, like the slot of a cable-line, and carried small wheels which could be changed in position at the pleasure of the motor-man, and the rotation of which by contact with the revolving pipe communicated motion to the car. The speed was regulated by varying the angle at which the small revolving wheels were set. After an expenditure, it is said, of many thousands of dollars, this device proved a failure, and has been abandoned.

Nearly half a century ago the engineering profession was entertained with occasional notices of a so-called atmospheric railway, which consisted of a pipe 36 inches, more or less, in diameter, laid under ground. On the top was a continuous slot, 2 inches wide, covered by a flap-valve of leather, rubber, or other elastic material. Inside the pipe was a piston carrying an arm through the slot like the arm of the grip in a cable-car. By exhausting the air in front, the atmospheric pressure behind would communicate motion to the piston, and as it moved the arm would open the flap-valve, which would close again behind it as it passed. A trial of this plan was made about 1840, on the West London Railway, and also on one or two other railways, but all were soon abandoned as unsatisfactory.

The result of these trials clearly proved that the atmospheric railway system could not stand in competition with that of the locomotive engine, unless in some peculiar situations. *Chambers's Encyclopedia* refers to this contrivance, and states that the expense and care necessary to keep the tube with its valve in good working order led to the removal of the atmospheric mechanism from the various railways on which it was established, so that the history of atmospheric railways may be ranked under the chapter of failures. They survive only in the form of pneumatic dispatch tubes for the conveyance of parcels, many of which are used in London.

After fifty years, and in the face of this experience, it is calculated to promote a smile to read a notice in the papers of "*A New Motor*," and of the existence of a pneumatic power and motor company, which has revived the old atmospheric railway scheme, with the difference that, instead of the continuous slot and elastic flap-valve, the slot is covered by a continuous row of rigid slide-valves, which are opened by a projection in the power-bar as the piston passes along the tube, and closed by a similar device after its passage. There is no reason to believe that this device can be more effective than the old flap-valve; but, on the contrary, must be more difficult and expensive to construct and maintain, and the loss by leakage in a continuous line of valves must be excessive.

GENERAL SUMMARY

Pneumatic and Compressed Air Motors.—More space has been given to the consideration of this subject than to any of the other forms of motors and systems of operation, for the reasons that it is the one upon which, in the mind of the public, the greatest ignorance prevails, and the one to the investigation of which the writer has devoted the greatest amount of time and attention.

The pneumatic motor presents the following advantages:—

It is the cheapest of all the systems in cost of plant and of operation.

It can run on any surface, elevated or underground tracks, and requires no trolleys or cables, no subterranean or overhead constructions.

The motors are all independent, so that no derangement of machinery at the central station can affect the line. The engines and compressors being in a number of units, repairs to one will not affect the rest.

There are no live feed wires to shock or kill men or horses, or by contact with telephone or telegraph wires, to communicate fires to buildings or shocks to occupants.

There are no obstructions to the free use of fire apparatus.

There are no dynamos to be burned and disabled during electrical storms.

There are no broken strands of cable to entangle grip bars and cause wrecks of cars and accidents to street vehicles.

There is no necessity, as in gas motors, to keep the machinery in constant motion.

There is no loss, as in hot water, steam, or ammonia, by radiation or condensation, but the charge in a motor will remain until used.

There is no serious loss by transmission of the power from a central station even to a distance of miles.

The speed is practically unlimited except by municipal restrictions.

No paying space for passengers is occupied either by air reservoirs or motor machinery. The reservoirs are under the seats and the machinery under the floor.

There is a surplus of power to ascend grades or overcome extraordinary resistances of brief duration.

Extra cars can be provided to any extent required by the exigencies of the service without reducing the length of the run, as the trail cars can carry their own charges of air in reservoirs under the seats.

A street blockade, or detention from any other cause, cannot reduce the capacity for propulsion. No reservoirs of fuel or water are required in transit, and the stored power remains intact until used, however long the period of suspension.

A peculiar feature of the Hardie motor not possessed by any other, so far as known, is that in descending grades, or whenever the motor cylinders are called into use as brakes, they act as air pumps, and, instead of using air, pump back an additional supply into the reservoirs.

The fuel required for a given amount of propulsive energy in pneumatic motors costs less than one-fourth as much as an equal amount in steam motors for similar service, and this cost is covered by seven mills per car mile.

Five of the Hardie pneumatic motors were in active daily use for several months on the Second Avenue street railroad in 1879, and furnished the data upon which the computations in this volume were based and the results determined. From such results, based on repeated daily observation, there can be no reason for withholding confidence.

The tests of the motor constructed for the Second Avenue Elevated Railroad in New York were certified to by the chief engineer of the Manhattan L Railroad, who is now engineer of the Chicago and South Side Railroad; by the former train-master of the Manhattan L Railroad and master mechanic of the Suburban Transit Company of New York, and now superintendent of the Chicago and South Side Rapid Transit Company, and by the foreman-machinist of the locomotive repair shop of the Second Avenue Elevated Railroad. These certificates referred to the actual performance in hauling the regular passenger trains upon the Second Avenue Railroad making twenty-three station stops, and show that every requirement was fulfilled.

There was also an award of the medal of superiority by the judges of the American Institute in 1878. There was also an expression of entire confidence in the performance of the machine by Messrs. Burnham, Parry, & Williams of the Baldwin Locomotive Works, and a still stronger statement from Charles T. Parry, one of the firm, who considered the system not only practical, but particularly well adapted for use in cities and towns; he enumerated the advantages, and claimed superior economy in cost of repairs, as there was no excessive heat to burn out certain parts.

If a system can justly claim the possession of every advantage that could be considered desirable, free from any conceivable defect, and at the same time more economical than any other, why has it not been universally adopted?

The answers have been given. They will be briefly repeated.

The public was not ready for the adoption of the system in 1879. Presidents of horse-railroad companies were afraid to allow cars to run without horses in front, thinking that the horses in the street would scare, cause accidents, and that suits for damages would be instituted. Efforts to induce them to have experts make examination of the merits of the system proved fruitless, and were abandoned.

There was a general misapprehension in regard to the loss of power in compressing air, and directors of companies could not be made to understand that this loss was compensated more than fourfold by economies in other directions.

But the principal difficulty arose from the fact that the men who formed the Pneumatic Tramway Company were neither capitalists nor practical men. They had secured a transfer of the patents from the inventor, Robert Hardie, for a stock consideration; had capitalized this stock at one million dollars, divided amongst themselves; they sold some shares to build five motors for street service; borrowed money to build the elevated railway motor at the Baldwin shops, could not pay the notes when due; lost the control of the patents, which became tied up in the estate of a deceased creditor, and the result was an abandonment of the entire enterprise. Hardie lost his patents, his stock became worthless, and he accepted the position of superintendent of a locomotive works, and has been working at a salary ever since.

This explanation will perhaps furnish reasons why the best system for either ordinary or rapid transit in cities has never been adopted on a practical scale in the United States, although an inferior pneumatic motor, the Mekarski, has been for many years in successful use in Europe.

There can be no patent either upon the use of compressed air as a motive power, or upon the combination of compressed air with a reheating apparatus to increase its efficacy. Patents can be granted only on new mechanical devices or combinations to utilize the energy of the compressed air. The old patents have about expired, and even if they possessed a sufficient number of years of vitality to obstruct progress in the use of air motors, they have been superseded by new and improved devices, so that parties using compressed air motors need be under no apprehension of trouble from litigation on

the part of holders of the original patents.

The only practical questions of importance are, can we calculate with certainty the amount of air that will be required at a given pressure for a given length of run, and can this air be furnished at an estimated cost that can be relied upon?

The first of these questions has been settled by the daily tests upon the Second Avenue Railroad. It has been positively determined that 300 cubic feet of free air when compressed will suffice to run a motor of the dimensions and weight there used for an average distance of one mile. If the round trip should be 12 miles, the reservoir capacity must contain 3600 cubic feet of free air plus a sufficient amount to retain an effective working pressure on the return. Consequently, if the cars are to be dispatched at intervals of one minute with a run of 12 miles, the compressor plant must have a capacity of 3600 cubic feet of free air per minute. If at intervals of 2 minutes, 1800 cubic feet; if at intervals of 4 minutes, 900 cubic feet; if at intervals of 6 minutes, 600 cubic feet; and if at intervals of 10 minutes, 360 cubic feet per minute.

As to the second question, the Norwalk Iron Works Company, the Ingersoll Rand Rock Drill Company, and several others will furnish compressor plant at fixed and reasonable prices and guarantee performanance, so that there can be no reason to apprehend disappointment from under-estimates of the engine power required, the quantity of air compressed in a given time, or the fuel consumed and cost of compression. The extensive use of compressed air for rock-drilling, tunnelling, and other purposes, has led, since 1879, to great improvements in compressors, and removed all elements of uncertainty in regard to their operation.

A very important observation may be added, that if it should be considered desirable after a road has been some time in operation, to increase the plant and to run the cars at shorter intervals, no difficulties are presented. The power is supplied, not by a single large boiler and engine, but by a battery of boilers and several engines, and the compressor plant also consists of a number of units; so that if the building is properly planned, additions and extensions can be made indefinitely as the increase of business may require.

APPENDIX.

Judson Low-pressure Air Storage System.—This is a system to which the attention of the writer has recently been directed. Its claims, as set forth in a pamphlet issued by the Judson Pneumatic Street Railway Company, are almost identical with those of the high-pressure system already fully described. The principal differences consist in the use of air at a pressure of 200 pounds to the square inch instead of 500 pounds, and arrangements for replenishing the supply in transit, at intervals of a mile, from reservoirs under the track connected with the central, or power station, by means of a 4-inch pipe. So far as public accommodation, safety, and economy are concerned, there is practically no difference between the high and low-pressure systems. Of course, high pressure requires stronger cylinders for storage than low pressure; but by increasing the thickness of metal the factor of safety can remain the same, and for a given storage capacity the high pressure will admit of reduced size of reservoirs. It is preferable, however, to make the storage capacity as large as possible without encroaching upon available space for passengers. The Judson is simply a modification of the low-pressure air system described on page 138.

From the pamphlet referred to, it appears that the claims of the Judson Company, on which the operation of the motors depends, are identical with those of the Hardie motor of 1879, and consist of storage tanks under the seats, reducing valves to reduce pressure before admission to motor cylinders, and a reheating apparatus.

The estimate of cost of plant and of operation differs materially from the estimate on the high-pressure system on pages 101 and 102, for the reason that the conditions and data given as the basis of calculation are very dissimilar. When similar conditions are assumed, the differences disappear.

The estimate of the Judson system is made on a double-track road $7\frac{1}{2}$ miles long, with 100 cars in constant motion, running at an average speed of $8\frac{1}{2}$ miles per hour. Weight of car, 6 tons; number of passengers, 50; consumption of free air, 50 cubic feet per car-ton per mile; surplus, 20 per cent.; allowance of air per car-mile, 420 cubic feet; for the 100 cars, 42,000 cubic feet per mile, or 6000 cubic feet per minute compressed to 200 pounds; 3 sets of compressor plant of 750 horse-power each = 2250 horse-power; coal consumption, 2 pounds per horse-power, or 4500 pounds per hour; cost of compressor plant, $90,000; time of running, 20 hours; cost per day, which includes only coal and service at station, $221; cost per car-mile, with interest on plant, 2 cents; daily mileage of cars, 170 miles; cost per car-mile for coal and service, $1\frac{3}{10}$ cents.

As the estimate for cost of power in the high pressure system was $4\frac{1}{10}$ cents (page 142), it might seem, from the above statement, that the low-pressure system was superior in economy; but the statement exhibits the usual disparity of conditions, and when brought to a standard of uniformity the differences disappear.

Coal, per horse-power—Low pressure, 2 pounds; high pressure, $2\frac{1}{4}$ pounds.

Daily mileage of each car—Low pressure, 170 miles; high pressure, 96 miles.

It may be a question, also, whether heavy falls of snow, or formation of ice around or in the feed nozzles between the tracks, might not cause trouble in winter for the low pressure system; but if it should, no doubt a remedy could be found.

On the whole, therefore, the Judson system may be considered preferable to any other now used or proposed except the high pressure, which takes its charge of air for the whole run, requires no intermediate reservoirs, and no pipe for the whole length of the track for the transmission of power. It is only in case the system should be extended to long inter-urban lines that pipes and intermediate reservoirs would become necessary, and to such lines the high-pressure system would be well adapted.

The low-pressure estimate of cost of power, $1\frac{3}{10}$ cents, included, as stated, only the cost of coal and the service at station. The high-pressure estimate, on the contrary, included also cost of repairs of station plant and of street motors; in fact, every item connected with power. Estimating only coal and service in the high-pressure system, the cost would be 1.48 cents per car-mile for a run of 96 miles per day; and if the average run were taken, as in the low-pressure system, at 170 miles, the cost per car-mile would be reduced, and still more if 2 pounds of coal were allowed to a horse-power instead of $2\frac{1}{2}$ pounds.

It is not claimed, however, that there are any such radical differences between the high and low-pressure systems as would result in any considerable difference of expense. In this regard the two systems may be considered as practically equal. The only important question is, Which is preferable? to use a pressure of 500 pounds and run a motor 12 miles without re-charging, or to use a low pressure that will require recharging every mile? the difference in cost of charging the reservoirs being, as shown on page 55, only 1 mill per car-mile.

That Man Haupt

A Biography of Herman Haupt

JAMES A. WARD

p. 212-13

In 1879 he also became interested in the use of compressed air for streetcar motors. He was asked to examine and make a report on a new compressed-air motor invented by Robert Hardie, a Scotch engineer, and constructed by the Pneumatic Tramway Company. Hardie had built five motors in 1878 and arranged for the Second Avenue Railroad in New York City to test their reliability and performance in daily traffic. Haupt was asked to observe the operation and to estimate the costs of conversion to compressed air for existing streetcar companies and the costs of constructing new systems run exclusively on compressed air.[62]

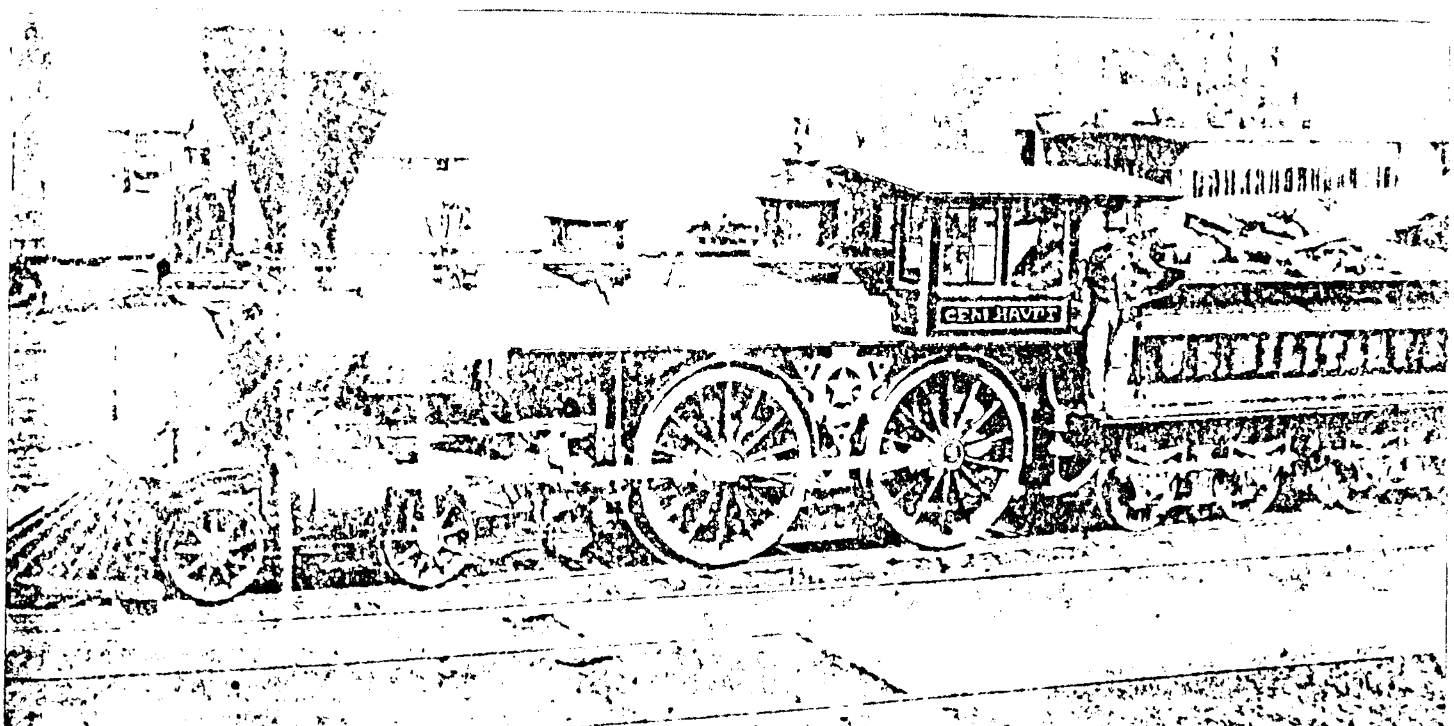
Haupt had investigated the manufacture and uses of compressed air while working on his rock drill and at that time had not been impressed. But in his report of February, 1879, he was enthusiastic over the possibilities offered by Hardie's motor for urban transportation. He watched the tests over a period of several months and concluded that if there was a very small rise in the number of passengers, the road could make a satisfactory profit while charging only 2.5 cents per ticket.[63]

Despite the projected savings resulting from the use of compressed air, the horse car companies refused to consider adoption of the idea because, as Haupt stated later, "Public opinion was not sufficiently educated to regard

this improvement with favor. Absurd as the objection then made may now appear, presidents of horse rail road companies declared . . . that the system could not be used without stuffing the skins of dead horses and running them on a low truck in front."[64] But this was not the only reason for the failure of the system. A group of promoters formed a dummy company to manufacture and sell the motors. These men capitalized the firm at one million dollars and appropriated the stock themselves without payment, an unlawful transaction. To evade the illegalities, the patents on the motors were given a value of a million dollars and purchased from Hardie for a stock consideration in the company. The managers then hypothecated the patents for loans they were unable to pay, and when the company folded it also lost the patents.[65]

It is not known whether Haupt invested in this company, but he may have been involved in a small way, for when the compressed air company was reorganized in the 1890s, he owned some stock. He probably was involved in the original patent development, for he received a patent himself on an improved compressed-air motor in conjunction with George H. Reynolds, a New York City engineer.[66] Haupt never acknowledged any royalties, nor is there any evidence that his motor was actually tested. His reports confined themselves to an analysis of the Hardie motor.

62 Herman Haupt, *Street Railway Motors. . . .* (Philadelphia, 1893), 61.
63 Herman Haupt, "Compressed Air for Street-Cars," *The Engineering Magazine*, III (1892), 621.
64 New York *Sun*, March 28, 1897; Haupt, *Street Railway Motors*, 107–108.
65 Haupt, *Street Railway Motors*, 108–11.
66 *Annual Report of the Commissioner of Patents for the Year 1879* (Washington, D.C., 1880), 156.



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Anna Cecilia's death had an unexpected effect upon Haupt. Although grieved over the loss of his wife after an exceedingly harmonious and loving relationship of fifty-two years, he did not become morose or introspective. Rather, he once again became professionally active. Freed from worry about his wife's health, and perhaps bewilderingly lonely, he took up new interests, renewed old acquaintances, published his *Reminiscences*, made some investments, traveled again, and became a social commentator.

The engineer in Haupt reawakened first. In 1892, he had a chance meeting with Robert Hardie, the inventor of the compressed air motor upon

which Haupt had reported in 1879. Hardie was now working as a mechanical engineer in preparation for the opening of the 1893 Columbian Exposition in Chicago.[15] Still an energetic promoter of his motors, Hardie imbued Haupt with some of his enthusiasm during a long technical discussion. Haupt unearthed the results of his 1879 experiments with Hardie's motor and wrote an article extolling its technical superiority and economy; the article was published in *Engineering Magazine*, in August, 1892.[16] After the publication of the article, Haupt spent the winter of 1892 examining the feasibility and the cost of adapting different types of motive power to streetcars. He summarized the results of his lengthy investigation in a book, *Street Railway Motors*, published in 1893. In it he predictably touted compressed air as the superior mode of urban transportation.[17]

The publication of his book did not diminish the popularity of electric streetcars, but it did persuade a group of men to form the General Compressed Air Company, hire Haupt as consulting engineer, and construct several full-size experimental motors in Rome, New York.[18] With a little financial backing, Haupt began in earnest to instruct the public about the advantages of compressed air. His book was followed by a pamphlet published in March, 1894,[19] summarizing the conclusions in the book. Later in the year he published *Rapid Transit in New York*, an open letter to Abram S. Hewitt, ex-mayor of New York City and chairman of the Rapid Transit Commission.[20]

Haupt's open letter to Hewitt was prompted by the Rapid Transit Commission's debate over the construction of a subway system for the improvement of the rush hour traffic flow.[21] Haupt had failed to impress streetcar companies in Philadelphia with compressed air (probably because one of the companies was run by his old antagonist, Thomas Ackley), and he had also been unable to secure its adoption in Boston.[22] The debate in New York gave him a chance to popularize the concept of compressed air by broadcasting copies of his open letter and granting interviews to all willing newspapers.[23]

Late in 1895 Haupt wrote another long technical paper, *Long Distance Transmission of Power;* in it he attempted to strike at the source of cheap electricity by discrediting the plans to transmit it across New York state from the proposed hydro-electric power plant at Niagara Falls.[24] He corresponded with electrical engineers on the subject and concluded that electricity could only be transmitted cheaply if it was in the range of twenty thousand volts; beyond that point insulators broke down and expensive transformers were required.[25] Haupt proposed that the falls, instead of generating electricity, be used to operate air compressors. Using the formulas he had derived for the transmission of fluids through pipes for the Tide Water pipeline, he calculated that compressed air could be transmitted through pipes for distances of up to one hundred miles much more economically than electricity could cover the same distance through wires. He suggested that compressed air could be transmitted to towns and used to operate local electrical generators.[26]

But Haupt was unable to slow down the growing popularity of the electric motor. Despite successful tests of the Rome compressed air motors on the 125th Street Elevated Railway and his publication of yet another article in the *Journal of the Franklin Institute* in 1897, New York City refused to adopt Haupt's plans. The general introduction of compressed air

remained only a dream so long as no capital was forthcoming.[27] He purchased an unknown amount of stock in the General Compressed Air Company and served as its consulting engineer until the end of March, 1898. By then the company was in such poor financial condition that it could not even pay Haupt for his last four months of service. From November, 1897, until the end of March, 1898, he was also president of the American Air Power Company; his salary was five thousand dollars per year, but he never received a cent of it.[28] Neither of the compressed air companies was ever listed on any stock exchange.

15 New York *Sun*, March 28, 1897.
16 Herman Haupt, "Compressed Air for Street-Cars," *Engineering Magazine*, III (1892), 617–22.
17 Haupt, *Street Railway Motors*, 190.
18 New York *Sun*, March 28, 1897; notes made by Haupt, 1898, in Yale Haupt Papers, Box 18.
19 Herman Haupt, *Relative Cost of Steam, Compressed Air and Electricity for the Operation of Railroads* (Washington, D.C., March 23, 1894).
20 Herman Haupt, *Rapid Transit in New York. . . .* (Washington, D.C., 1894); Allan Nevins, *Abram S. Hewitt With Some Account of Peter Cooper* (New York, 1935), 470, 528.
21 Nevins, *Abram S. Hewitt*, 503.
22 Letterhead, Ackley to Haupt, March 18, 1880, in Yale Haupt Papers, Box 7.
23 Abram S. Hewitt to Haupt, November 13, 1893, in Haupt Papers, Minnesota Historical Society, Minneapolis; George B. Roberts to Haupt, December 11, 1894, *ibid.*; George S. Boutwell to Haupt, January 1, 1895, *ibid.*
24 Herman Haupt, *Long Distance Transmission of Power* (New York, 1895).
25 *Ibid.*, 4.
26 *Ibid.*, 21. 36.
27 Herman Haupt, "Compressed Air for City and Suburban Traction," *Journal of the Franklin Institute*, CXLIII (1897), 13–26, 119–32.
28 Notes made by Haupt, 1898, in Yale Haupt Papers, Box 18; Haupt to Ellen Haupt Chapman, November 10, 1896, *ibid.*, Box 9.

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By the year of his death, Haupt was convinced that his system of American values was being subverted by collusion for personal gain between financiers, corporation executives, and politicians. His moral indignation at this discovery, however, did not obscure for him the basic dilemma posed by this alliance; in order to break down the power of business and finance, the federal government's regulatory powers would have to be increased. This proposition was inimical to Haupt's *laissez faire* business philosophy. In either situation, he realized, basic individual freedoms would be curtailed. But in his last correspondence it was evident that he was moving towards the necessity for government intervention in the business world as a counterbalance to corporate and financial rapacity. It is not inconceivable that had Haupt, a man born into an America mesmerized by the Jeffersonian concept of limited government, lived until 1912, he would have stood with Teddy Roosevelt and his Bull Moosers on the floor of the Chicago convention hall and joined the chant, "We stand at Armageddon and we battle for the Lord."

Herman Haupt was a major figure in the development of American railroads during the nineteenth century. Civil engineer, entrepreneur, administrator, promoter, and investor, Haupt was a remarkable man. An engineering graduate of West Point, he helped to construct and operate the Pennsylvania Railroad in the 1850s and rose high in the company's ranks. He spent six years attempting to bore the Hoosac Tunnel in Massachusetts, but was forced to suspend the work and lost his fortune.

During the Civil War, Haupt was director of Union military railroad operations in the eastern theater where he won the rank of brigadier general. After the war he became—in rapid succession—chief engineer for the Shenandoah Valley Railroad, general manager of the Pennsylvania Railroad's southern interests, chief engineer and designer of the first long-distance crude-oil pipeline, and general manager of the Northern Pacific. Despite his achievements, however, Haupt never recovered his Hoosac losses.

Until his death in 1905 at the age of eighty-eight, he worked as a consulting engineer investigating various technical innovations and promoting those in which he had an interest.

"Compressed Air for City and Suburban Traction," Herman Haupt, *Journal of the Franklin Institute*, January. 1897, p. 13

Although a considerable amount of compressed air literature has been given to the public during the last two years, there is still a want of information as to the efficiency and economy of air motors as compared with cable, electric and other systems, and statements are continually published in the columns of the daily press that exhibit ignorance of scientific facts and apprehension of imaginary dangers.

Compressed air motors have been in successful operation in France for many years, and they are now rapidly establishing themselves in public favor in the United States. They have been constructed and tested at Rome, New York, continuously for two years, in all conditions of weather, and have given satisfaction even at temperatures below zero.

Several motors are now, and have been, running for some months on the One-hundred-and-twenty-fifth Street Railway, in the city of New York, in daily service, without having lost a trip and with great satisfaction to the public.

The attention of the writer was first directed to the use of compressed air for city service in 1879, when he was called upon to examine, test and report upon several motors that had been constructed under the supervision of Robert Hardie, and allowed to be run on a portion of the Second Avenue Surface Railway, at Harlem, in New York. These motors were tested for several weeks, and the results were entirely satisfactory; but all attempts to secure their introduction proved fruitless. There was so strong a prejudice against them, that the president of one of the city railroads in Philadelphia declared that he would not have such a motor on his road if it saved the whole cost of horse-power; that it would frighten every team on the street to see a car running without horses, and the company would be perpetually annoyed by lawsuits. Explanations proved useless, and efforts were abandoned.

After the far more objectionable and expensive cable and trolley systems had been introduced and had demonstrated that a car could be run without horses and without frightening teams, the writer renewed efforts to educate the public, and especially the profession, in regard to the superior merits of compressed air. A book was published,* giving a description and comparative cost of all the systems known or used for city

This was followed by a number of monographs on special points, and finally resulted in the formation of a syndicate to raise capital and organize a company under the title of the General Compressed Air Company. The services of Mr. Robert Hardie were secured as engineer, and a motor constructed at the Rome Locomotive Works, which proved entirely successful from the start, and has been examined, tested and favorably reported upon by engineers, experts and scientists from all parts of the United States without exception.

Very erroneous opinions have been and are yet entertained in regard to the power lost in compressing air, the frost produced in expansion, the danger of explosion, the reheating of dry and moist air, the cost of plant, the necessity for frequent renewals of air supply, the possible length of run, the loss by transmission of air to distant points, and other matters connected with the practical application of air as a motor.power.

That the subject of air motors may be intelligibly presented, it is necessary to state briefly some of the properties of air and the laws which govern its compression,

* Street Railways Motors, Herman Haupt, London: Henty Carey Baird & Co., 1893.

expansion and distribution, also such of the properties of steam as enter into the consideration of the questions at issue.

Physical Properties of Air and Steam.

Air at a temperature of 32° F. requires 12.433 cubic feet to weigh 1 pound; at ordinary temperature about 13 feet.

The weight of steam at 212° is 26.4 cubic feet to the pound, or approximately, for rough calculation, 26 feet. *Specific heat*, or capacity for heat, varies with different substances, and it is a very important element in calculations in thermodynamics. Water, having the greatest capacity for heat, that is, having a capacity to retain the greatest number of heat units per pound, has been taken as the unit of specific heat. On this standard, the specific heat of air is .2377, or approximately .24.

The specific heat of steam is .475, or approximately .48, or double the specific heat of air. In other words, steam is half as heavy as air, but has double the capacity per pound for retaining heat.

If air be suddenly compressed to one-half its volume, the temperature will be raised 116° and if suddenly expanded to double its volume the temperature will be reduced to the same extent.

Under high pressure a given increase of pressure will develop much less heat than at low pressure. For example, a given volume of air at atmospheric pressure, condensed suddenly to one-half by an increase of pressure of 15 pounds, would develop 116° of heat, while under a pressure of 25 atmospheres an increase of pressure of 1 atmosphere would raise the temperature only 16.7°

A thermal unit, or unit of heat, is the quantity of heat that will raise the temperature of 1 pound of water 1°, and a thermal unit is the equivalent in work of 772 pounds raised 1 foot.

A horse-power is 33,000 pounds raised 1 foot in 1 minute.

Isothermal compression is compression without evolution of heat. If this were attainable in practice, as much energy could be utilized in the expansion of air as was expended in compression.

Adiabatic compression is compression with evolution of heat. By compression and intermediate cooling it is claimed that 80 per cent. efficiency may be obtained. Under old systems of compression the loss has been conceded to be 50 per cent. The capacity of air for holding moisture is affected by volume and temperature, but not by density. A cubic foot of air will hold no more water at the same temperature under 133 atmospheres than under 1; consequently, when this air is expanded to original tension, 1 cubic foot will contain only 1/133 part of the moisture that it had originally and should be too dry to form a deposit of ice at the exhaust even if not reheated. Only low pressures can contain sufficient vapor to cause trouble; but as air should always be reheated, for reasons that will be explained, the difficulty from frost is purely imaginary.

Absolute or theoretical zero is a point determined by theory 461° below the zero of Fahrenheit, from which temperature must be estimated in problems connected with expansion of elastic fluids, the volumes being in proportion to the temperatures from absolute zero. This datum will be found essential in considering the question of reheating.

Latent heat is the heat that disappears or becomes latent in change of form, as from a solid to a fluid, or from a fluid to a vapor, and which reappears by condensation when the original condition is resumed.

In the liquefaction of ice 142.5 units of heat per pound become latent, and in the conversion of water into steam 966 units; so that the latent heat of water from ice is 142.5 units, and of steam 966°.

The specific heat of ice is .50, so that the number of thermal units in 1 pound of steam at 212°, measured from absolute zero, will be $(461 + 32) \times .50 + 142.5 + 180 + 966 = 1{,}535$ units.

An apology for these explanations and definitions seems to be required, as they apparently assume a want of information on the part of the reader, but there seems to be a necessity for explanations to remove the ignorance and prejudice that are almost universal. Even in technical journals, articles have appeared from the pens of gentlemen of high scientific reputation advocating the reheating of *dry* air to increase its power, and giving plans of apparatus for the accomplishment of this object. It will be shown that to double the power of dry air by an application of heat is practically impossible, and that it is only by an admixture of vapor that satisfactory results can be secured,yet this demonstration could not be given without furnishing the data which it required.

AIR COMPRESSORS.

The use of compressed air for the operation of rock drills and for other purposes has become so extensive that it has led to great improvements in compressors, and several companies are now engaged in their manufacture who will furnish plants at moderate prices and guarantee results. Among these can be named the South Norwalk Iron Works Company, the Ingersoll Sargeant Drill Company and the Rand Drill Company. The best results are secured by repeated compressions with intermediate cooling, and large plants should always consist of a number of units, so that repairs to one will not affect the remainder, and the number in use at one time can be regulated by the demands of the traffic.

The experience gained by numerous tests, extending over a period of years, has furnished positive and reliable data by which to determine the amount of free air, under compression, required for any given service under any ordinary conditions. If responsible manufacturers of compressors will agree to furnish the plant at a given price, with a guarantee to compress a given number of cubic feet of free air per minute, delivered in station reservoirs under a given pressure, with a coal consumption and horse-power within prescribed limits, all elements of uncertainty as to cost of power seem to be removed; and this is being done.

The improvements in compressors have greatly increased their efficiency and extended the use of compressed air. In the primitive types an efficiency of 50 per cent. only could be secured; now 80 per cent. is claimed, while the ability to transmit power by this agency to long distances without serious loss, and to concentrate many small powers into a general reservoir will permit many water-powers to be utilized that would otherwise be worthless, and secure economies not offered by any other system.

The sudden compression of air is attended with a great evolution of heat. To compress two volumes of air into one, as previously stated, will raise the temperature 116°; but it is a remarkable and valuable property of air and other elastic fluid, that under

high pressures a given increase requires less power and develops less heat than under low pressures.

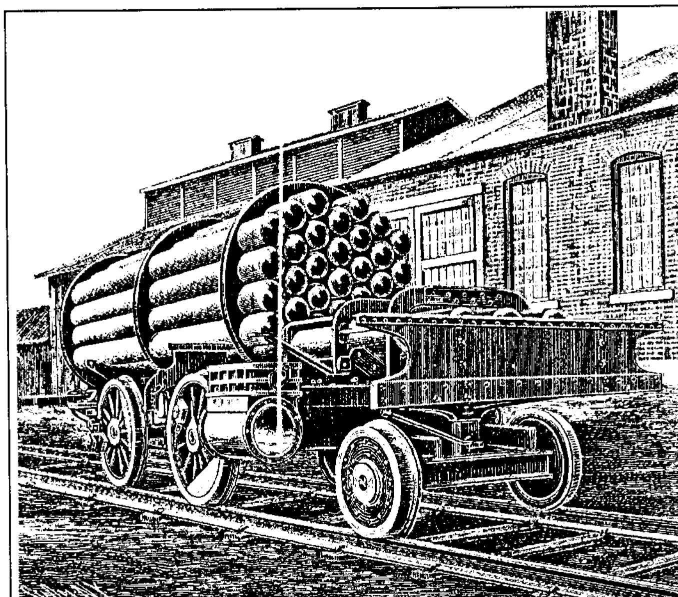
If, for example, it should be required to compress 3,600 cubic feet of free air per minute to a pressure of 500 pounds, the horse-power required would be 1,060 horse-power; if to 1,000 pounds the power would be 1,219 horse.power—a difference of 159 horse-power for 500 pounds; if to 1,500 pounds pressure, 1,288 horse-power, or a difference of 69 horse-power for 500 pounds; and if to 2,000 pounds, 1,339 horse-power, or a difference of only 51 horse-power to gain 500 pounds of additional pressure.

The power required to compress 1 cubic foot of free air is estimated as follows:

	Horse-power.
To 500 pounds pressure per minute	0.316
To 1,000	0.364
To 1,500	0.385
To 2,000	0.400

To which 10 per cent. allowance should be made in practice in allowing actual power for compressors.

Mr. E. Hill, the General Manager of the Norwalk Iron Works, gives absolute isothermal compression to 2,000 pounds per square inch per cubic foot of free air per minute, 0.315 horse-power, and the best possible in practice under the most favorable conditions, 0.378 horse-power. The computation of the writer gave 0.348 horse-power as the theoretical isothermal, but 0.45 should be allowed in practice. It is better to provide an excess of power than to suffer the inconvenience of a deficiency.



View of motor in course of construction, showing battery of compressed air storage flasks.
(Scientific American, January 30, 1897)

RE-HEATING.

A remarkable property of compressed air is that its efficiency can be doubled by re-heating. This is not theory; the fact has been confirmed by actual demonstration, both in Europe and America. It may appear incredible and contrary to well-known physical laws that the efficiency of air can be doubled by simply passing it through a tank of hot water before admission to the motor cylinders, but such is the fact, and the reheating which doubles the power represents a consumption of coal only one-eighth of the amount required at the power station to produce the compression.

A direct test was made at Rome, on motor No. 100, in the presence of Capt. G. J. Fiebeger, of the U. S. Engineers, now Professor of Civil Engineering at West Point. The consumption of re-heated air from an average of many runs was 308 cubic feet per mile. When the re-heater was emptied of water, the volume of cold air required was 669 cubic feet per mile.

An explanation of this remarkable result will be given.

A comparison will be made between the results of reheating dry air to an extent sufficient to double its volume with and without the assistance of water, assuming the volume at 60° to be 300 cubic feet of free air, and that it is to be admitted to the motor cylinders under a pressure of 150 pounds to the square inch.

Assume, in the first place, that air at 60° is passed through a tank of water at 360°, giving a steam and air pressure of 150 pounds per square inch. The units of heat required to double the volume will now be determined.

The absolute temperature at 60° is 60 + 461 = 521°.

The absolute temperature at 360° is 360 + 461 = 821°, so that the air passing through water at 360° will be increased in volume, or under constant volume will be increased in pressure 63 per cent.

The thermal units required for the increase of temperature will be, 23 pounds of air raised 300°, specific heat of air being .24. Then 23 × 300 × .24 = 1,656 units. The air has been increased in pressure 63 per cent., and to double the pressure by the addition of vapor or steam from the water will require the addition of 111 cubic feet of steam at atmospheric tension. That is, the 300 cubic feet of air at atmospheric tension has been increased to 489, and 489 + 111 = 600. The 111 cubic feet of steam weighs 4.3 pounds, to secure which from water at 360° requires only the latent heat, or 863 units. 863 × 4.3 = 3,711, and adding the 1,656 units previously obtained, will give a total of 5,367 units.

Coal completely consumed will furnish 13,000 units per pound, petroleum 20,000 units per pound, and allowing for loss by imperfect combustion, 1 pound of coal or ½ pound of petroleum should furnish the fuel for re-heating at a cost of 2 mills for coal or 1¼ mills for crude petroleum, and 300 cubic feet of air thus re-heated should run an 8-ton motor much more than 1 mile.

To double the volume of air by the application of dry heat, the temperature must be double from absolute zero. At 60° observed temperature the absolute temperature would be 60 + 461 = 521°, and the double would be 1,042°, and deducting 461° would leave the equivalent thermometric temperature 581°, a degree of heat that would burn out the lubricants and would be entirely inadmissible. In fact, it is stated in a recent work on compressed air by Mr. Frank Richards, that to double the power with dry air would require a temperature of about 800°, in consequence of the low specific heat of air and consequent rapid cooling.

As the air is supposed to be used expansively, so that the atmospheric tension is reached at the end of the piston stroke, the quantity of heat lost by expansion with an initial pressure of 10 atmospheres, or 150 pounds, would be 494°, which is nearly all that the heated air contained, so that if the admission could be at 581°, the exhaust would be 87°, without allowance for loss by radiation or conduction, and so much heat would be absorbed by the cylinder that the efficiency of the re-heated air would be greatly impaired.

On the other hand, if the air be passed through hot water, any vapor condensed in the cylinder yields its latent heat and steam, also acts as a lubricant.

Another striking comparison will be presented. Steam at 350° temperature and 150 pounds pressure, will, in cooling down to 212°, impart more than thirty times as much heat to the cylinders as an equal weight of air between the same temperatures.

Degrees F.	Cubic Feet.
At 321	35.2
At 300	42.5
At 296	43.3
At 274	48.5
At 259	95.2
At 210	159.0
At 190	238.0
At 182	229.0
At 170	221.0
At 164	459.0
At 158	493.0

The difference of temperature is 350 - 212 = 138°. Specific heat of steam, .475; air, .24.

	Units.
1 pound of steam yields 138 ×.475	65.5
and of latent heat	966.0
Total heat from 1 pound of steam	1,031.5
1 pound of air reduced 138° yields 138 × .24	33.12

One pound of steam carries as much heat as 31 pounds of air, and not only serves with little loss to maintain the cylinder and passages at a proper temperature, but, as previously stated, it also serves as a lubricant.

The reasonable conclusion is that it is practically impossible to heat dry air to an extent sufficient to double its power, and if practicable it would be inexpedient and the effect highly injurious.

The ideal re-heater would be a tank containing water at a temperature to furnish steam at the pressure of the air as used in the motor cylinders. The heat retained constant and uniform by cheap fuel, such as crude petroleum, and in winter the cars to be heated by water circulation from the same tank.

From tests made by him in 1879, the writer concluded that the average amount of water absorbed by the air and carried over in the form of steam was about 1 pound for 50 cubic feet of air. The accuracy of this result having been questioned, Mr. Hardie was requested to make a series of tests at Rome, the result of which established the fact that the quantity of water absorbed and carried over was dependent upon the temperature. At a high temperature in the water a comparatively small volume of air would suffice to evaporate a pound, and at a low temperature the volume of air was greatly increased.

The table [above] is interesting, showing the number of cubic feet of air at atmospheric tension required to absorb and carry over 1 pound of water in the form of steam or vapor.

RESERVOIRS.

The subject of reservoirs is one of the most important in connection with the construction of compressed air motors. The reservoir is the source of power in the motor, and upon its capacity and strength the possible length of run depends. Formerly, reservoirs were constructed of riveted boiler plates, and were capable of sustaining a pressure of from 300 to 600 pounds per square inch only. Consequently, a run of over 10 miles required so great an extension of capacity that room could be secured only by raising the floor to an inconvenient height above the rails. To secure long runs, with moderate reservoir capacity, high pressure is a necessity, and reservoirs are now manufactured, by a peculiar process, from solid ingots of mild steel, without a joint or weld, and which are capable of sustaining with safety a pressure of 2,000 pounds per square inch, the test, within the limits of elasticity, being carried to 4,000 pounds, leaving so large a factor of safety as to render rupture impossible.

It is proper to observe that the risk of rupture is not greater under a pressure of 2,000 pounds than it would be under 500 pounds, for the thickness of the shell would be four times as great with the higher pressure, and the strain per square inch of metal would be precisely the same in both cases.

Paradoxical as it may seem, it can be shown that a pressure of 2,000 pounds per square inch is actually more safe than a pressure of 500 pounds, notwithstanding the fact that newspaper scribblers, in the interest, apparently, of rival systems, to create a prejudice against compressed air, magnify the risks of an explosion and the dangers to result therefrom.

Bear in mind that all reservoirs intended to carry 2,000 pounds are tested to 4,000 pounds, within elastic limits; consequently, the pressure could be increased 2,000 pounds more before the danger limit could be reached.

But if the pressure were 500 pounds the margin of safety would be the same, and the test would be to 1,000 pounds. Consequently, a variation of 500 pounds increase of pressure would reach the danger limit with the low-pressure reservoir, but would be 1,500 pounds below this limit with the high pressure. There can be no question of the sufficiency of the margin of safety.

But if, notwithstanding the theorizing upon the subject, the reservoirs should actually burst, would not the consequences be disastrous ? The answer is no! A rent would be formed and the air would escape with a hissing noise. The material, unlike cast iron, is ductile and will stretch and pull apart and not fly in pieces.

The following extract from a letter from the manufacturers in Germany, addressed to the writer, will afford an explanation:

"Regarding the reservoirs, we put them to a test yesterday to state the elastic limit. It was reached at 3,500 pounds, but we went further in our experiments in order to demonstrate by practical test (as it has been demonstrated in hundreds of bursting tests of carbonic acid bottles) that these air bottles would not crack or fly to pieces, but that they would simply open when the breaking strain was reached (as was always the case with the carbonic acid bottles, when tested to bursting strain) and allow the contents to flow out, proving thereby that the handling of these bottles is in no way dangerous. We, therefore, think it advisable and safer for the future practical use of the bottles, not to test them, as we mutually agreed, till near to the bursting strain, but only till near to the elastic limits, because we are afraid that although they stand the test till near the bursting strain,

the metal is somewhat weakened and, therefore, the practical use afterwards diminished. You will find the bottles somewhat lighter than ordered, and the question to decide for future deliveries will be whether you want the bottles as light as possible and use a storage pressure of 1,500 pounds per square inch, or if you prefer to make them somewhat heavier and use a storage pressure of 2,000 pounds per square inch. Please answer if you agree to the above, and we will send you the whole lot immediately. To-day we send you eight bottles, seven medium long and one short one, that you may, if you choose to do so, repeat the test to 3,500 pounds. As the fluctuations of the compressed air pressure, caused by the fluctuations in the atmospheric temperature are small when compared with the same fluctuations of the carbonic acid, we think it safe to test the air bottles only to the elastic limit,and use them with about half that pressure in practical work, as this way is safer than to test the bottles to the bursting strain and charge them only with one-third of that pressure afterwards in practical use."

Similar results have been indicated by tests in other localities, and it must be remembered that the rupture of a cylinder containing air produces effects that are widely different from those which result from the explosion of a steam boiler. When a boiler explodes, the volume of steam may be instantly increased more than a thousandfold by the conversion of water into steam by the reduction of pressure, the boiler is ruptured and pieces of iron and scalding water projected to great distances, while the rupture of an air cylinder allows a comparative moderate expansion of the contents, accompanied by a sensation of cold and not of heat.*

WEIGHT OF RESERVOIRS.

The weight of reservoirs is in proportion to the number of cubic feet of free air that they inclose, and that again is in proportion to the length of run, and is entirely independent both of diameter and pressure.

The truth of this position can be demonstrated rigidly, but a simple explanation will suffice to make it clear.

Suppose a reservoir of any diameter, say 1 foot, is under a pressure of 2,000 pounds per square inch, 1 foot in length of such reservoir will weigh a certain number of pounds.

Now, suppose the diameter should be reduced to one-half or 6 inches, the thickness of metal to resist the pressure would be one-half as great as formerly, and the circumference also one-half, consequently the weight per foot would be one-fourth; but to secure equal capacity the cylinder must be four times as long, and, therefore, the weight, with a given capacity, must be the same whatever the diameter.

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* To illustrate more clearly the effect of the explosion of a steam boiler, let it be assumed that the dimensions of the boiler are 3 feet diameter and 12 feet long, containing 85 cubic feet, of which 70 cubic feet are water and 15 cubic feet of steam at a temperature of 350°.

The 70 cubic feet of water will weigh 4,375 pounds, and at 350° will contain 1,531,250 units of heat.

The 15 cubic feet of steam at 15 atmospheres will weigh 9 pounds and contain 10,602 units, and the whole contents of the boiler 1,541,870 units of heat.

Let x = quantity of water at 212° not converted into steam by the explosion. Then 4,375 - x = water converted into steam at 212° Latent heat, 966 units. Then 212 + (4,375 - x) 966 + 10,602 = 1,541,870. From which x= 3,600 pounds, and 4,375 - 3,600 = 775 pounds of water converted into steam by the explosion = 20,176 cubic feet, 20,176 + 225 = 20,401 cubic feet of steam liberated, and 20,401 + 15 = 1,360 times the original volume of steam which has been increased by the explosion.

Again, suppose the pressure should be reduced from 2,000 to 1,000 pounds per square inch, the weight to resist this pressure would be reduced one-half, but to contain the same quantity of free air the capacity must be doubled, and, consequently, the weight would be the same as before.

It follows, therefore, that whatever may be the diameter of the reservoir or the pressure per square inch, the weight of reservoir to enclose a given *weight* of air will be constant.

What then is the weight per cubic foot of interior capacity required to resist a pressure of 2,000 pounds per square inch, equivalent to 136 cubic feet of free air?

If 35,000 pounds be assumed as the elastic limit of the material, and one-half, or 17,500 pounds, as the maximum strain upon the metal per square inch from an interior pressure of 2,000 pounds, then it will be found that the weight per cubic foot of interior capacity will be 115 pounds. The weight of the last importation of the German reservoirs was 106 pounds per cubic foot of interior capacity.

As the 115 pounds per cubic foot under 2,000 pounds pressure contain 136 cubic feet of free air compressed into 1 foot, the required weight of reservoir will be 0.856 pound for each cubic foot of free air that may be enclosed.

If, in addition, it should be assumed that 400 cubic feet of free air should be provided to run an 8-ton motor 1 mile, with sufficient allowance for contingencies, the weight of reservoir per mile run would be 338 pounds. This weight, it must be understood, applies to the motor only, and is the equivalent of 42 pounds per ton of motor weight. Trail cars will require only about one-third as much per ton.

RESULTS OF TESTS.

Compressed air motors have long since passed the experimental stage. They have been running for two years at Rome, N. Y., and through the kindness of the officials of the New York Central Railroad have been repeatedly allowed to run on the main track, where a speed has been attained of 30 miles per hour with wheels of only 26 inches diameter.

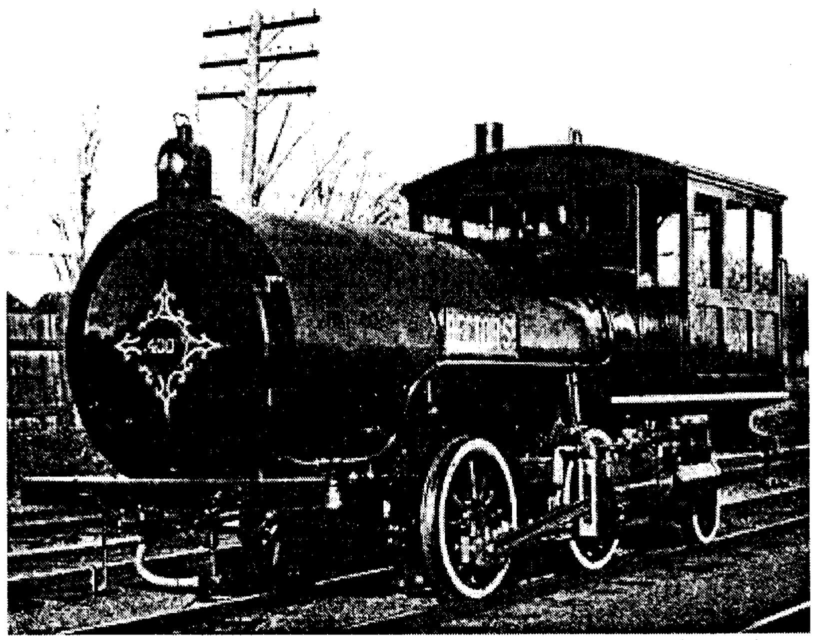
It should be obvious to every person of intelligence that a compressed air motor can be planned to fulfill any conditions, or perform any service, within the capacity of a steam locomotive. Speed requires large wheels, length of run large storage. High grades and heavy trains require large cylinders. The motor must be adapted to its work and fulfill the conditions of its service.

Tests have been made repeatedly by engineers and experts from all parts of the country, all of whom, without exception, have made favorable reports. One of these tests, made in the presence of the writer and of Captain Fiebeger, of the U. S. Engineers, February 18, 1895, gave the following results:

Starting with a pressure of 1,900 pounds in motor, and temperature of 291° in the water of the reheating tank, the first six runs of 4,800 feet were made on an average of 221½ cubic feet of free air per mile.

The next six runs of 4,800 feet, temperature 252°, required an average of 339 cubic feet per mile.

The water in the tank was then reheated, by attaching a steam hose, to 302°, when the next run was made on an average of 208½ cubic feet per mile, from which the required quantity of air increased as the water became colder to 377 cubic feet per mile.



Hardie compressed air locomotive for the Manhattan Elevated Railway. (Engineering News, June 24, 1897)

After the tenth run, the water was again reheated, and the quantity of air fell per mile to 247 cubic feet, and then increased to the fifteenth and last run, when the temperature was 247° and the quantity of air per mile 521 cubic feet.

The average expenditure of air during the whole test was 308 cubic feet per mile. When the water was emptied from the tank and cold air used, the consumption was 661 cubic feet per mile on the same track.

This motor was calculated to run a maximum distance of 12 miles, with one charge of air, but as the reservoir capacity was 35 cubic feet, under 136 atmospheres, the cubic contents of free air was 5,760 cubic feet, which, divided by 308, gives 18.7 miles as the possible run if all the air could have been used. Allowing 2.7 miles as a reserve, there would still have remained an effective run of 16 miles. There can be but little doubt that by an efficient system of reheating, whereby the temperature could be maintained at 300°, a greater efficiency could be secured.

It is unnecessary to give the results of other tests; they have been quite numerous, and by different experts, and confirm substantially the conclusion above stated.

The motors now running daily on the One-hundred-and-twenty-fifth Street railway in New York make 17 miles with one charge of air. The reservoir capacity, 50 cubic feet.

Why is compressed air cheaper, both in installation and in operation, than any other system of traction for city and suburban service ?

It requires less power at the power station for a given service, and this means less cost for engine plant and a perpetual saving in coal consumption.

	Per Cent.		*Per Cent.*
Engine friction	8	Remains	92.0
Belting and shaft	10	"	82.5
Dynamos	8	"	76.2
Transformers at power station	7	"	70.9
Line to sub-station	12	"	62.4
Transformers at sub-station	7	"	51.8
Rotary converter	16	"	48.8
Railway circuit	10	"	43.8
Car motor	15	"	37.2

A comparison with the trolley must be based on similar conditions, and as the recognized maximum distance of transmission of electrical power under 500 volts is 5 miles, a line of 5 miles, double track, with two-minute headway, will be assumed as a basis of

comparison, average speed 10 miles per hour, and 30 motors on line.

Electrical motors are usually supplied with two 25 horsepower motors, making 50 horse-power each, but as the full power is required only in overcoming the maximum resistances, the power provided at the power station is usually calculated upon a basis of transmission of 25 horse-power for each motor.

This transmission involves many losses, and only a comparatively small portion can be actually utilized at the rail.

In the Engineering News of October 17, 1895, p. 256, is found an estimate [see above table], the indicated power of the engine at the power-house being taken at 100.

This estimate gives only 37.2 per cent. of the indicated power at the station as effective at the rail but as other estimates claim a higher efficiency, it will be assumed as 50 per cent.

The thirty motors on the track will therefore require 1,500 horse-power as the prime mover at power-house.

Thirty air motors, with a run of 10 miles, will require 4,000 cubic feet of free air, or 2,000 cubic feet per minute, compressed to 2,000 pounds, and the horse-power at the station will be 900, or 600 less than with electricity, and there is no loss in transmission.

COMPARATIVE COST OF MOTORS.

It is usually claimed that the cost of compressed air motors is considerably greater than the cost of electrical motors for equal service.

This is a mistake; the comparison must be made under like conditions. The compressed air motor carries its power with it. The electric motor takes it from the line. A fair and just comparison requires that the cost of plant to furnish power on the line should be included or omitted in both cases.

Omitting the reservoirs, estimates for the air motors have been brought below the electric motors, notwithstanding the low price of the latter, due to active competition; but allowing the cost to be the same in both systems, a comparison will be made between the reservoirs for thirty motors and the line construction required to furnish the electrical power for an equal number.

The thirty air motors will require 110,000 pounds of reservoir, costing about $15,000; per motor, $500.

The cost of line work for 5 miles of double track, with thirty motors, will be $26,000; per motor, $866.

POWER PLANT.

Another great saving is effected in the cost of power plant. It is usual in electrical estimates to allow $80 per horse-power at the power station, exclusive of land and buildings for engines, boilers, shafting, belts, dynamos and other apparatus.

The cost of 1,500 horse-power, at $80 per horse-power, would be $120,000.

Compressed air requires no dynamos, belting or shafting. Steam from simple boilers is piped directly to the compressor, and it would be an excessive estimate to assume that the cost is one-half that of electricity, or $60,000.

SAVING IN TRACK.

The track for air motors requires no girder rails or electric binding or welding. A simple cross-tie track, as is used for ordinary locomotives, is sufficient. The reason for this is that the weight on the air motor is spring-supported, and on the electric motor a much heavier load is rigidly attached to the axle. From a table furnished to the writer by Franklin L. Pope, it appears that the effect of a blow of 1 ton from a wheel passing over an obstruction 1/8 inch in height, at a speed of 20 miles per hour, is twenty-seven times as great when the weight is rigidly attached as when it is relieved by springs.

The saving with compressed air increases with the magnitude of the plant. Without encumbering this paper with detailed estimates, it is proper to state that the writer prepared a close estimate of the relative cost of electricity and compressed air for a transmission of 5 miles from the power station on an elevated railroad, such as the Third Avenue Railroad, in New York, with trains running at one minute intervals. The estimate for electricity was submitted to a prominent electrical engineer and pronounced correct. The cost was more than double that of the compressed air installation. In fact, the return electrical current could not be transmitted in the ordinary way by rail, but would require some special arrangement. The attempt to reduce the cost of copper by increasing the voltage of transmission is attended with great increase of risk to life.

A system that may prove satisfactory on a small scale and with a limited volume of business may result in failure if extended beyond certain limits. President Vreeland, of the Metropolitan system, in New York, in an interview recently published in the Herald, pronounced the underground electric system in Lenox Avenue unsuited for a line with a heavy business. It required sometimes from two to four days to locate a defect, which, when found, could be remedied in ten minutes. In selecting any system for adoption, the sensible course is always to get estimates in detail from competent and unbiased engineers, covering every point of installation and of operation, and then find responsible contractors to guarantee the work within the limits of the estimates.

MOTIVE POWER PER CAR MILE
(run 120 miles per day).

	Cents.
Anthracite coal for compressor plant	0.870
Anthracite coal for reheating	0.110
Water, boiler-feed, etc.	0.022
Oil, waste, etc.	0.024
Removal of ashes, etc.	0.014
Operating labor	0.615
Maintenance of power plant, etc.	0.163
Maintenance of motors, etc.	0.280
Interest and general expenses	1.760
	3.858
TRANSPORTATION.	
Maintenance of cars, trucks, buildings	1.619
Motormen, conductors, etc.	6.133
General expenses, interest, etc.	1.155
	12.765
Electricity, similar items included, costs	16.268
Difference, 27 per cent.	3 503

COST OF OPERATION.

It has been shown that the cost of installation of a compressed air system is much less than that of the ordinary cheap trolley with

wooden poles. If it can be shown also that the operation is more economical, then there can be no question as to its superiority in this particular over the cable, underground electric and other systems, all of which are much more expensive than the trolley.

The following [table] is the latest revised estimate of an engineer long connected with electric companies and familiar with all details of operation, but at present engaged in the introduction of compressed air installations.

SOME INTERESTING FACTS.

By reheating the air required for the operation of a motor, the efficiency may be so much increased that more power may be utilized in the motor cylinders than was expended at the power station in the compression of the air.

This statement has often elicited a smile of incredulity as it seems to be in violation of the law of the conservation of energy, but it is susceptible of a simple explanation.

Take the horse-power at the compressor, say 1,400 horsepower to compress 3,600 cubic feet of free air per minute to 2,000 pounds, the foot-pounds in 10 hours would amount to 5,544,000,000.

The number of motors that this amount of air would supply is 120, assuming cylinders 6 × 14 inches; wheels, 26 inches in diameter; speed, 6 miles per hour; consumption of free air, 300 cubic feet per mile; pressure, 140 pounds per square inch, cut off at one-tenth stroke; mean pressure, 46.2 pounds per square inch. These conditions would give 6,802,272,000 foot-pounds of work in the cylinder of the motors, or 22 per cent. more than the foot-pounds of power expended at the compressor.

How can this be explained? Simply by the reheating of the air, which increases its volume and by the steam which accompanies it and adds greatly to the effect.

But if air is reheated and steam used as an auxiliary to increase the effect, will not the expense of reheating fully offset any advantages thereby secured ?

COST OF REHEATING.

From tests made in 1879, it was found that for 50 cubic feet of free air passed through the reheater, 1 pound of water, in the form of steam, was absorbed; 300 cubic feet of air would, therefore, absorb 6 pounds of water. Under a pressure of 140 pounds, the temperature would be 353°, or for effective pressure of 140 pounds, the absolute pressure would be 160 pounds and temperature 364°. The latent heat at this temperature is 858°.

The heat units required to raise 6 pounds water from 60° to 364°, including the latent heat, will be 1,162 × 6 = 6,972 units. To raise the temperature of 300 cubic feet of air 23 pounds, from 60° to 364°, specific heat of air being 0.24, will be 304 × 23 × 0.24 = 1,678 units.

The total units required for reheating for 1 mile will, therefore, be 6,972 + 1,678 = 8,650 units, which would be supplied by four-fifths of 1 pound of coal, at a cost of 1-1/5 mills.

This coincides very nearly with Mr. Hardie's experience, that the cost of reheating was about one-eighth the cost of compression.

EXPANSION IN REHEATING.

Fifty cubic feet of dry air carries over 1 pound water, which in steam, at atmospheric tension, gives 52 per cent.

Air at 60° F., heated to 364°, will expand in proportion of 461 + 60 to 461 + 364, or 521 to 825, which is 58 per cent. Total increase of volume, 110 per cent. Hence, 300 cubic feet will become 633 cubic feet. Without reheating the water on the trip, the Hardie motor, at Rome, consumed 331 cubic feet per mile, 110 per cent. of which would be 695 cubic feet. The actual consumption of dry air was 661 cubic feet.

INFLUENCE OF SPEED IN CONSUMPTION OF AIR.

A very general, but very erroneous, impression appears to exist in regard to the increased consumption of air in traction motors, due to an increase of speed.

It is assumed that the consumption of air must be in proportion to the horse-power, and as the space passed over in a given time must be doubled, the horse-power, in which space is a factor, must be doubled, and the consumption of air doubled also.

This is true, but the consumption of air per mile is not doubled by doubling the speed. The consumption of air is in proportion to the resistances to be overcome, and within reasonable and ordinary limits these resistances are but slightly increased by increase of speed. It is an error, also, to suppose, as many do, that in trolley motors an electrical attraction between the wheel and rail increases adhesion.

In support of these positions, authorities will be quoted. Oscar T. Crosby, in Transactions of American Institute of Electrical Engineers for August and 1894, states: "The adhesive coefficiency between the wheel and the rail is not increased in any practical degree by the passage of the current. In other words, there is no electrical attraction, as some suppose, between the wheel and the rail to increase adhesion. The adhesion is due to the weight on drivers alone."

The train resistances at high speeds do not increase, as is usually supposed, as the square of the velocity. At 86 miles per hour the total resistance per ton was only 13.4 pounds; 347 tons were carried at 86 miles per hour on a line by an expenditure of 1,068 horse-power.

The resistance of the air is a function of the first instead of the second power of the velocity.

From 40 to 80 miles per hour, the tonnage coefficient is practically 8 pounds per ton on first-class roads and best rolling stock.

Wellington, in his popular work on engineering; pages 922-924, makes statements as follows:

"Journal friction is variable, and is usually taken at 8 pounds per ton.

"The load per square inch on journal bearing has very little influence upon the friction.

"The velocity of the lowest journal friction is from 10 to 15 miles per hour.

"With good lubrication there is very little increase of journal friction up to 55 miles per hour.

"The coefficiency of journal friction is approximately constant at velocities from 15 to 50 miles per hour.

"The power required to overcome inertia and accelerate trains is about three times as much as to maintain velocity.

"The additional power required to get up speed is 45 pounds per ton to give 15 miles per hour in 3,340 feet.

"The air resistance at 10 miles per hour is less than 1/5 pound per square foot.

"The principal resistance, except axle resistance, is due to oscillation and concussion, which, at 10 miles per hour, may be taken at ½ pound per ton."

The above quotations from standard authorities do not sustain the statement of the expert of the General Electric Company, who stated in a criticism upon an estimate of the writer, that "a calculation, which it is not necessary to enter into, will show that to make an approximation to the average speed of 20 miles per hour, 600 horse-power will be found *not* sufficient to do the work. Where the speed of an electric train is reduced to that assumed for the steam train (10 miles per hour) 300 horse-power will be found abundantly sufficient."

The inference would appear to be, that if the speed of an electric train is increased from 10 to 20 miles per hour, the power must be increased from 300 to 600 horse-power. If this be true, it is very bad for electricity, for it is not true in regard to either steam or compressed air. The power required must always be sufficient to overcome resistance, and if, as appears from the authorities quoted, the resistances are but slightly increased by increase of velocity, there cannot be any great increase of power required per mile of distance traversed as measured by consumption of air or steam. There must be some, of course, but in ordinary service it does not figure very largely in the expenses.

As practical tests are more satisfactory than theory, the writer requested Mr. Hardie to make a test of the consumption of air at different speeds, and report the result. The table is the report, under date of April 22, 1896.

The above results are very remarkable. The ordinary pressure gauges are not very sensitive, but it is impossible, from the table, to infer that there was any increased consumption of air per mile, either with a largely increased speed or a considerable increase of weight. When a train is in motion, the draw-bar pull is but slightly increased by a moderate increase of speed. The great losses of power are in acceleration and retardation in starting and stopping.

FIRST TEST. LOAD, 19,150 POUNDS.

Speed	*Cu. ft./mi.*
3.00 miles per hour, consumption of air	 347
5.70	 334
6.81	 488
7.57	 335
7.80	 568
8.50	 452
9.70	 388
10.10	 560
10.30	 275
11.40	 604
12.30	 421
13.00	 538
13.70	 447
16.70	 450
17.05	 447
22.80	 445

SECOND TEST. LOAD, 24,990 POUNDS.

12.27 miles per hour, consumption of air	 334
15.34	 449

THIRD TEST. LOAD, 26,100 POUNDS.

6.70 miles per hour, consumption of air	 437
8.00	 452
10.34	 470

FOURTH TEST. LOAD, 36,000 POUNDS.

5.25 miles per hour, consumption of air	 632
7.50	 582
8.56	 589
15.34	 334

It has been stated that the power required on a good track to start a street car is 116 pounds per ton, and to maintain it in motion 13 to 17 pounds. On a bad track, 134 pounds to start and 35 pounds to maintain.

Mr. Hardie has found by tests upon his motor that 130 successive applications of the brake consumed, by gauge pressure, 85 cubic feet of free air, equivalent to 0.65 cubic feet for each application.

Franklin L. Pope is authority for the following statement:

"A 16-foot trolley car,weighing about 14,000 pounds, requires eighteen seconds to get up speed and 10 horse-power to run 10 miles per hour, or 1 horse-power per mile per hour at car axle. Three times this power is required during the eighteen seconds of starting."

Frank S. Sprague, in New York Evening Post, of February 8, 1896, states that on the Third Avenue Elevated Railroad the maximum effort in the propulsion of trains is seven times the mean traction on a level; and that to start a train, accelerate to 20 miles per hour and bring it again to rest, consumes eighty seconds.

David L. Barnes estimates that an elevated train of 130 tons can be accelerated to 30 miles per hour in a distance of 1,250 feet, and brought to rest in half that distance.

OTHER USES FOR COMPRESSED AIR.

Compressed air affords the most economical means for the transmission of power to long distances. It has been claimed that electrical power generated from waterfalls could be transmitted hundreds of miles, but the writer has attempted to show in a monograph that is too voluminous to quote, that in the present condition of the science, power by electricity cannot be economically transmitted in competition with power furnished locally by coal, to a greater distance than about 20 miles. Long electrical transmission requires excessively high voltages, which are almost impossible of permanent and successful insulation, and instantly destructive to life in case of accidental contact. The late lamented Franklin Leonard Pope, in a letter to the writer, used this language: "A voltage of 20,000 may be possible in the future, but it has not yet been successfully accomplished. The difficulties seem to increase roughly as the square of the voltage; 10,000 volts is a wicked acting current, and when you double it, you had better watch out." He also adds: "The same speculative boomers who have put in 300 nonpaying electric railroads throughout the country are now at work fostering a craze on electric power transmission. I am sorry to see it, for it will end in discrediting all legitimate electric work. The mass of people will never learn to discriminate between the practicable and impracticable."

The transmission of compressed air requires high pressures, for the reason that increased pressure gives increased density and reduced volume and velocity. The loss in transmission being as the first power of the density and the square of the velocity, the loss in transmitting under 200 pounds would be ten times as great as under 2,000 pounds. High pressures are necessary for economical transmission both with electricity and air.

But compressed air and electricity are not properly to be considered antagonists; they may be made valuable auxiliaries.

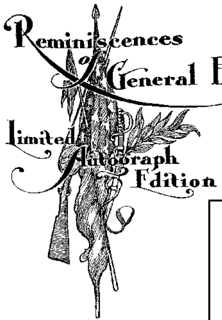
A 6-inch pipe under an initial pressure of 2,000 pounds per square inch, and a terminal pressure of 10 atmospheres, or 147 pounds, will transmit nearly 8,000 horse-power to a distance of 10 miles, 5,700 horse-power to 20 miles, and 2,500 horse-power to

a distance of 100 miles. Where there are mountain streams furnishing small powers at frequent intervals, a number can be concentrated in one pipe, and transmitted to furnish large power in distant localities. Compressed air, thus economically transmitted, can be used to generate electricity for local purposes. It can also be distributed to provide small powers, and also for ventilation and refrigeration in towns and cities.

The cable and electric systems, it is well known, are operated to best advantage economically at full capacity, but this is only for a few hours in the day. If surplus power were used to store air at high pressure in reservoirs the machinery could be shut down entirely or partially, and compressed air motors substituted at night and during the hours when full capacity is not required.

ELASTICITY OF THE SYSTEM.

An important advantage of compressed air motors is found in the fact that each motor is independent, and unaffected by any derangement of feed or trolley wires, cables or dynamos. They can run on any line, in connection with any other system, and at any rate of speed. The introduction of air motors can be gradual; one motor can be tried, and, if satisfactory, the number can be increased to a full equipment. The steam required for electric or cable lines can furnish the little that is required for an experimental compressor, and will be more than sufficient for a full equipment. No outside expenditure whatever is required—no conduits, poles or wires. In this respect it differs from other systems, and permits a test to be made at a minimum of cost; but compressed air motors can no longer be considered as experiments. While they may not have attained the utmost limit of perfection of which they are capable, the experience in Europe, in Rome, N. Y., and in the City of New York, should be sufficient to satisfy the most skeptical.



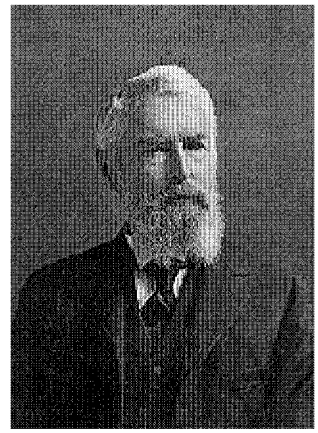
GENERAL HERMAN HAUPT.

GENERAL HAUPT, now in his 85th year and the active head of an important manufacturing enterprise in the United States, is one of the most interesting, as he certainly is one of the most remarkable, figures in our history.

Few men have participated in so much that has contributed to the growth and grandeur of our country, yet how little the world knows of his career, how reluctant the trumpeters have been to herald his achievements !

A designer and builder of roads and bridges; a constructor of railroads and tunnels; a professor and author; an inventor and master mechanic; a military strategist and civil counsellor; a railway manager and canal engineer; a manufacturer and organizer of great enterprises; a military and civil engineer, still up-to-date and a leader of progress, he links the old with the new, the slow and sleepy past with the swift and dashing present in a way that is entirely exceptional.

He was born in Philadelphia on March 26, 1817. His father, Jacob Haupt, died in 1828, leaving a widow and six children.



Who was General Herman Haupt?

REMINISCENCES

OF

GENERAL HERMAN HAUPT

Director, Chief Engineer and General Superintendent of the Pennsylvania Railroad
Contractor and Chief Engineer for the Hoosac Tunnel
Chief of the Bureau of United States Military Railroads in the Civil War
Chief Engineer of the Tidewater Pipeline
General Manager of the Richmond & Danville and Northern Pacific Railroads
President American Air Power Company
Etc Etc

GIVING

HITHERTO UNPUBLISHED OFFICIAL ORDERS,

PERSONAL NARRATIVES OF IMPORTANT MILITARY OPERATIONS,

AND

INTERVIEWS WITH PRESIDENT LINCOLN, SECRETARY STANTON, GENERAL-IN-CHIEF HALLECK, AND WITH GENERALS MCDOWELL, MCCLELLAN, MEADE, HANCOCK, BURNSIDE, AND OTHERS IN COMMAND OF THE ARMIES IN THE FIELD, AND HIS IMPRESSIONS OF THESE MEN

[WRITTEN BY HIMSELF]

WITH NOTES AND A PERSONAL SKETCH BY
FRANK ABIAL FLOWER

Illustrated from Photographs of Actual Operations in the Field

1901

Signed Herman Haupt

IN JULY, 1901.